NON-MORAIC SCHWA: PHONOLOGY AND PHONETICS

By

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ABSTRACT OF THE DISSERTATION

Non-moraic schwa: Phonology and phonetics

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This dissertation proposes that schwa can be non-moraic (Kager 1989, 1990, Féry 1995, 1996), analogous to high vowels. In addition, such moraless schwas can head syllables (called 'minor syllables' after Matteson 1965, Lin 1993, 1997, 1998, Shaw 1994, Gafos 1998). Non-moraic, monomoraic, and bimoraic schwa can co-exist in the same phonological system. One of the major empirical consequences of this theory is that it accounts for stress systems in which stress avoids schwa. I go further in claiming that non-moraic schwa is the only means by which stress systems are sensitive to vowel quality, contra Kenstowicz (1997), de Lacy (2002, 2004, 2006), and others.

I argue that non-moraic, monomoraic, and bimoraic schwa co-exist in Piuma Paiwan, an Austronesian language that has been reported to have sonority-sensitive stress (Chen 2009a, b, Yeh 2011). My fieldwork and experimental results provide acoustic evidence that stress avoids landing on a schwa. I argue that such avoidance is a side-effect

of schwa's prosodic status: schwa is usually non-moraic in Piuma Paiwan. However, schwa is required to be monomoraic when it appears in the non-head position of a foot, and bimoraic when it is forced to be in the head syllable of a foot. The different kinds of schwa have significantly distinct phonetic effects, particularly in duration and vowel quality variability.

The theory proposed here predicts that stress should never avoid non-central vowels. One of the major challenges to this prediction is found in sonority-driven stress systems that seem to make peripheral vowel distinctions. However, I will present experimental evidence that the most discussed example of such a system – Gujarati – has been described incorrectly (cf. de Lacy 2004). Of the five types of phonetic evidence examined, only F1 provides clear evidence for stress, revealing stress to be consistently penultimate, and not sonority-driven. I will also show that many descriptions of putative sonority-driven stress lack robust phonetic and phonological evidence. Finally, I present an Optimality Theory factorial typology of constraints relating to schwa moraicity, and identify important rankings for grammars with various effects.

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to know each other in various ways, and it is impossible to mention every detail here, I truly appreciate your interaction with me, either in academia or social life.

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Earlier versions of Chapter 4 appear as:

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In this dissertation, I propose an enriched moraic representation for central vowels, building on Moraic Theory (Hyman 1985, McCarthy & Prince 1986, Hayes 1989). In particular, schwa will be the focus of the dissertation, but the proposed representation applies to other central vowels, too (e.g. [ɨ]).

A central proposal is that there is a non-moraic counterpart to schwa, agreeing with Crosswhite (1999), Hyman (1985), Kager (1989), Féry (1995), Bensoukas (forthcoming), and others. When combined with the possibility that syllables may not have heads (i.e. 'minor syllables' – Lin 1998 and others), the following structures for (open) syllables with schwas are possible.

(1)   Syllables with schwa
        a. Minor syllable   b. Monomoraic schwa   c. Bimoraic schwa
        with nonmoraic schwa
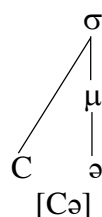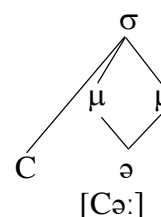
This dissertation will focus on the phonological and phonetic theory of minor syllables with non-moraic schwa, and its empirical consequences.

I will argue that the minor syllable schwa structure in (1a) comes about through a conflict between constraints that are violated when schwa bears a mora (i.e. *μ/ə), vs. those that require moras in specific environments.These include HEADEDNESS-σ, which requires syllables to have moras, and FTBINμ, which requires feet to be bimoraic. The tableau below shows how syllables with both moraic and non-moraic schwa are well-formedin the same system. Candidate (2b) wins because it has a moraic schwa (təᵘ) in the foot, as required by FTBINμ, and a non-moraic schwa outside the foot, as preferred by *μ/ə. The other candidates either flout *μ/ə by having too many moraic schwas (e.g. candidate 2c), or violate FTBINμ by failing to have bimoraic feet (candidate 2a).

(2)   Non-moraic and moraic schwa

/patəkə/	FTBINμ	*μ/ə	HEADEDNESS-σ
a. (páᵘ.tˤ)kˤ	*!		**
☞ b. (páᵘ.təᵘ)kˤ		*	*
c. (páᵘ.təᵘ)kəᵘ		**!	

A great deal of this dissertation is spent exploring the phonetic consequences of non-moraic schwa. I argue that non-moraic schwa is characterized by an extremely short duration, in close accord with Crosswhite (1999: ch.7). The phonetic effect is that non-moraic schwas are significantly shorter than moraic schwas, which are in turn shorter than bimoraic schwas. Evidence for the three types of schwa comes from my fieldwork and experiments on Piuma Paiwan, an Austronesian language spoken in Taiwan. I show in chapter 3 that all three types of schwa exist in this language.

A further phonological proposal is that markedness constraints are restricted in their internal structure, building on Itô & Mester (2003):

(3)   Hierarchical Locality restriction on markedness constraints

If a markedness constraint mentions prosodic node *p*, it may mention nodes at *p-1*

and *p-2*, but no nodes at other levels.

The formal effect of Hierarchical Locality is that there can be no constraints of the form

*HD_{Ft}/ə, which is violated when a root node with the sonority of schwa is dominated by

the head mora of a head syllable of a foot. This constraint refers to prosodic levels three

tiers apart (Ft vs. root node), and so cannot exist in CON.

The empirical effect of Hierarchical Locality is that there is no direct reference from

the metrical level to the level of vowel sonority. Consequently, the ability of stress systems

to refer to sonority levels is severely restricted. In fact, I demonstrate that the only way

that stress can be sensitive to sonority is via non-moraic schwa. The theory therefore

predicts the following:

(4)   Predictions about sonority-driven stress

a. Stress may avoid schwa, but only if it is non-moraic

b. Stress may not avoid any other sonority level

These predictions are at odds with a great deal of work on sonority-driven stress

(Kenstowicz 1997, de Lacy 2002, 2004, 2006). Chapter 3 shows how prediction (4a) works

by illustrating how non-moraic schwa causes stress to fall on a non-default position in

Piuma Paiwan. Chapter 4 addresses (4b) by looking at the most robustly attested case of

non-peripheral sonority-driven stress – Gujarati. I show that contrary to previous impressionistic descriptions, there is no acoustic evidence that stress avoids peripheral vowels. In other words, the only way in which stress can be sonority-sensitive is to avoid schwa, and it does so indirectly – via schwa's lack of a mora.

The rest of this chapter expands on the points made above. Section 1.2 discusses the proposals, section 1.3 outlines the empirical consequences, and section 1.4 outlines the rest of the dissertation.

1.2 Proposals

This section proposes the phonological representation of non-moraic and moraic schwas, and argues that schwa's moraicity is detectable via duration and variation in vowel quality. Section 1.2.1 proposes the phonological representation of non-moraic, monomoraic, and bimoraic schwa. Section 1.2.2 discusses the phonetic properties of different kinds of schwa.

1.2.1 Phonological proposals

Following previous studies, I propose that schwa can be non-moraic (Crosswhite 1999, Kager 1989, 1990, Féry 1995, 1996), and that a moraless schwa can head a 'minor' syllable (Matteson 1965, Lin 1993, 1997, 1998, Shaw 1994, Gafos 1998). For further discussion of previous work, see section 2.5 in chapter 2. Furthermore, I propose that non-moraic, monomoraic, and bimoraic schwas can co-exist in the same phonological system. The representational consequences of this proposal are given in (5), repeated here for convenience:
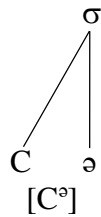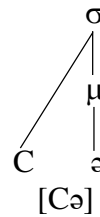
(5)   Syllables with schwa
        a. Minor syllable   b. Monomoraic schwa   c. Bimoraic schwa
        with nonmoraic schwa
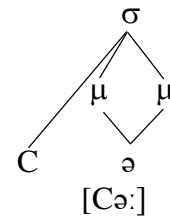
In (5b) and (5c), schwa is directly dominated by one and two moras, respectively. In contrast, in (5a) the schwa does not bear a mora; instead it is immediately dominated by a syllable node. Thus, (5a) is an instantiation of a minor syllable.

I argue that the motivation to have non-moraic schwa is the following constraint:

(6)   Constraints on moras and sonority levels (after Zec 2007, also see Prince & Smolensky 2004)

        *μ/ə   "Incur a violation for every schwa that bears a mora."

The constraint *μ/ə is part of the family of constraints *μ/ə, *μ/{ə,i/u}, *μ/{ə,i/u,e/o}, *μ/{ə,i/u,e/o,a}, which regulate the content of syllable nuclei.

In opposition to *μ/ə are constraints that require moras. In most direct opposition is the constraint HEADEDNESS-σ (HDσ), which expresses the tendency for prosodic nodes to dominate at least one node belonging to the tier immediately below it (Selkirk 1989, 1995):

(7)   HEADEDNESS-σ "Incur a violation for any σ that does not dominate a μ."

Other constraints can also require moras, but in specific environments. For example, FTBINµ requires feet to have two moras; it can force schwa to be moraic for foot-form purposes.

I argue that the moraic content of schwa is determined on a language-specific and contextual basis. Three possibilities arise. First, a language may only have non-moraic schwa. Second, a language may only have moraic schwa. Third, a language may have a mixture: non-moraic and moraic schwas co-exist in the same phonological system in different environments. The tableau below shows how such a typology can come about. Candidate (8a) has only non-moraic schwas, and can win if *µ/ə outranks both HEADEDNESS-σ and FTBINµ. Candidate (8b) has both moraic and non-moraic schwa, and wins in the ranking FTBINµ » *µ/ə » HEADEDNESS-σ. Candidate (8c) has only moraic schwa, and wins if HEADEDNESS-σ outranks *µ/ə.

(8)   Three possible schwa systems

/patəkə/	FTBINµ	*µ/ə	HEADEDNESS-σ
☞ a. (páᵘ.tᵊ)kᵊ	*		**
☞ b. (páᵘ.təᵘ)kᵊ		*	*
☞ c. (páᵘ.təᵘ)kəᵘ		**	

As I will show in chapter 5, Chuvash (also German and Dutch) is a potential candidate for the non-moraic schwa system, and Eastern Armenian for the moraic schwa system. Lastly, I will show that Piuma Paiwan has a mixed system, as can be seen in chapter 3.

The theory makes a variety of predictions about exactly which kind of mixed systems – i.e. systems with both moraic and non-moraic schwa – can exist. For example, using the constraints discussed in this dissertation, it is impossible to have a mixed system

where non-moraic schwas are required in the non-head of a foot, but moraic schwas are required outside feet (i.e. *[(páᵘ.tᵊ)kəᵘ]). An extensive typological survey is provided in chapter 5.

Another proposal made here is that prosody is myopic. That is, the form of markedness constraints that mention prosodic nodes is highly restricted. Specifically, I will argue that stress does not have access to vowel sonority, consistent with Itô & Mester (2003)'s proposal on hierarchical locality. The particular implemetation of the restriction is given above in (3), repeated here for convenience:

(9)   Hierarchical Locality restriction on markedness constraints

        If a markedness constraint mentions prosodic node *p*, it may mention nodes at *p-1*

        and *p-2*, but no nodes at other levels.

That is, within any given domain, only the immediately internal structure of the subjacent domain can be accessed. For example, foot-internal structure is visible at the Prosodic Word level, but sylalble internal structure (i.e. moraic structure) is opaque; only at the level of the foot can syllable-internal structure be directly accessed. Similar restrictions apply to higher prosodic domains. At the level of the phonological phrase, the internal structure of Prosodic Words will be visible, but not the internal structure of feet or syllables, and so on.

In contrast, sonority is not a subsegmental feature – it behaves like manner features, which McCarthy (1988) proposes inhabit the root node. As a result, the Ft level only has access to the levels of σ and μ in the prosodic hierarchy. The consequence is that there can be no constraints that directly connect feet and sonority levels, contrary to theories by

Kenstowicz (1997) and de Lacy (2002 et seq.).

The empirical evidence for this restriction comes from my experiments and fieldwork on Gujarati and Piuma Paiwan, both of which are claimed to have sonority-driven stress. Chapters 3 and 4 will show that stress is not influnced by vowel sonority. Instead, moraic content plays the crucial role in deternining stress position. The consequence is that there is no need to have prosodic constraints that directly connect feet to vowel sonority.

1.2.2 Phonetic proposals

It has been noted in many studies that syllables containing schwa are phonetically distinct from syllables containing full vowels. For example, Swedish schwa vowels are characterized by lower amplitude and shorter duration than full vowels (Lindblom 1963). However, much less attention has been devoted to the question of what the phonetic characteristics of schwa vowels are, as noted by Flemming (2009).

I propose that different kinds of schwa have distinct acoustic effects, particularly in duration and vowel quality variability. In these proposals, I follow Crosswhite (1999: ch.7) to a great extent.

(10)   Phonetic properties of schwa

Moraless schwa = minimal duration; large vowel quality variance.

Moraic schwa = longer duration; small vowel quality variance.

Bimoraic schwa = even longer duration; small vowel quality variance.

Moraic quantity determines duration (e.g. Hubbard 1995, Broselow *et al*. 1997), so schwa's duration is determined based on the number of moras. Here, I propose that bimoraic schwa is perceptually distinctively longer than monomoraic and non-moraic schwas, and monomoraic schwa is then perceptually distinctively longer than non-moraic schwa. Crucially, since non-moraic schwa has no moras at all, it has minimal (intrinsic) duration. The theory predicts that if any duration pattern is found that does not follow the moraic content just described, the duration observed will not be due to moras, but to some other duration-extending phonological or phonetic process (e.g. phrase-final lengthening). Detailed illustration is provided in chapter 3.

Second, I propose that non-moraic schwas have greater variation in vowel quality (F1 and F2) than moraic schwas. Several studies have noted that the quality of schwa is affected by the acoustic and articulatory properties of neighboring environments (e.g. Browman & Goldstein 1992, Koopmans-van Beinum 1994, Flemming & Johnson 2007, Flemming 2009). Van Oostendrop (2000) interprets this characteristic as evidence for the placelessness of schwa. However, duration can condition varaition in vowel quality (Lindblom 1990). Specifically, articulatory targets may not be fully reached, because there is insufficient time for articulatory movement. Since non-moraic schwa is significantly shorter than moraic schwa, non-moraic schwa therefore has less time for articulatory movement than moraic schwa. So, non-moraic schwa is predicted to show greater vowel quality variance than moraic schwa. Thus, variation in vowel quality, or phonetic undershoot, can be viewed as a phonetic property that is parasitic on duration.

In sum, I have proposed that duration and vowel quality variance can be used to detect different kinds of schwa. As I will show in chapter 3, the phonetic properties

mentioned above provide evidence for non-moraic, monomoraic, and bimoraic schwas in Piuma Paiwan.

1.3 Empirical consequences

I have proposed that there are non-moraic schwas (Kager 1989, 1990, Féry 1995, 1996), and that non-moraic schwa can co-exist with moraic schwa in the same phonological system. Some major consequences for the analysis of stress and vowel reduction follow from these proposals. As Crosswhite (1999) has discussed non-moraic schwa and vowel reduction in some detail (also see chapter 5), I focus on stress here. Specifically, the theory predicts that true sonority-driven stress systems do not exist, contra Kenstowicz (1997), de Lacy (2002, 2004, 2006), and others.

A 'sonority-driven' stress system is one where the relative sonority of syllabic nuclei is a factor in determining the position of metrical structure. The universal sonority hierarchy is given in (11) (Kenstowicz 1997, de Lacy 2002, 2004, 2007).

(11)   Universal sonority hierarchy (Kenstowicz 1997: 162, de Lacy 2002: 55)

low peripheral > mid peripheral > high peripheral > mid central > high central

'a'   'e, o'   'i, u'   'ə'   'ɨ'

Peripheral vowels are more sonorous than central ones, and within those groups lower vowels are more sonorous than higher ones.

The precise sensitivity of foot structure to sonority levels is language-specific. For example, de Lacy (2002) proposes that disyllabic words in Gujarati have the following

sonority hierarchy: | a > ɛ ɔ e o u i > ə |. That is, the low vowel [a] is more sonorous than non-[a] vowels, and full vowels are more sonorous than schwa. The effect is that while stress falls on the penultimate syllable by default, it will fall on the final or antepenultimate syllable if they contain [a] and the penult contains a less sonorous vowel. Examples are given in (12).

(12)   *Gujarati with sonority-driven stress* (data from de Lacy 2002: 72)

    a. Default stress on penult

      [sáɖa]   'plus ½'

      [dʒája]   'let's go'

    b. Stress falls on ultimate [a] if penult is a non-[a] vowel

      [ʃikáɾ]   'a hunt'

      [hɛrán]   'distressed'

    c. Stress falls on penultimate [a] if ultima is a non-[a] vowel

      [sáme]   'in front'

      [sáɖu]   'plain'

In (12a), stress falls on the penultimate syllable – the default position – when both vowels are [a]. However, stress is retracted to an [a] in the final syllable when the penult contains other vowels – all of which are less sonorous than [a], as in (12b). If the final syllable contains a vowel other than [a], stress falls on the penultimate position, as in (12c). In other words, since [a] is more sonorous than other vowels, it attracts stress away from the default position, so it is a case of 'sonority-driven stress'.

Furthermore, the typology of sonority-driven stress can be classified into two types: (i) stress which is sensitive to peripheral vowel distinctions, and (ii) stress which is solely sensitive to central vowels (schwa).

As discussed in section 1.2.1, I propose that prosody is myopic. Feet can directly 'see' the internal structure of syllables (i.e. moras), but not below the moraic level. In formal terms, there are no markedness constraints that mention both Foot nodes and root nodes or their properties. The empirical consequence is that stress cannot be sensitive to peripheral vowel distinctions, and so Gujarati cannot be accurately described as a 'sonority-driven' stress language.

I will argue in chapter 4 that there is no phonetic evidence for sonority-driven stress in Guajarati – the most well described case with peripheral vowel distinctions (also see Shih 2016, 2018). There is no acoustic evidence that stress ever falls on non-penultimate syllables. Chapter 5 further reviews all other cases of sonority-driven stress, and finds that the phonological and phonetic evidence for stress's sensitivity to peripheral vowels is either weak or non-existent.

However, the theory predicts that it is possible to have an 'apparent' sonority-driven stress system. In the present proposal, such a system comes about as a side-effect of non-moraic schwa. For example, in a language with default penultimate stress, if feet must be headed by a mora, stress will appear to 'shift' to a non-penultimate syllable if the penult contains schwa. The following two tableaux illustrate this situation. The first tableau shows how default penultimate stress comes about – through the action of ALLFTR, which requires feet to be rightmost; TROCHEE, which requires that the leftmost syllable in the foot be the head; and FTBINμ, which requires feet to be bimoraic.

(13)   Default penultimate stress

	/kato/	TROCHEE	ALLFTR	*μ/ə	HD-σ	FTBINμ
☞	a. (káto)					
	b. ka(tó)					*!
	c. (ká)to		*!			*
	d. (kató)	*!				

However, if the penult contains a schwa and the schwa is required to be non-moraic, the effect is that the foot can be compressed to encompass only the final syllable. The following tableau shows how this result comes about. The candidate [(kə́to)], with penultimate stress, fatally violates *μ/ə because it contains a moraic schwa. The candidate [(kᵊto)] has no foot head at all, and so violates TROCHEE. The candidate [(kᵊtó)] also violates TROCHEE because it has a right-headed foot. The last candidate standing is therefore [kᵊ(tó)], which avoids moraic schwa at the expense of having a degenerate foot on the final syllable.

(14)   Schwa in the default stress position

	/kəto/	TROCHEE	ALLFTR	*μ/ə	HD-σ	FTBINμ
☞	a. kᵊ(tó)				*	*
	b. (kə́to)			*!		
	c. (kᵊto)	*!			*	*
	d. (kᵊtó)	*!			*	*

In other words, when stress avoids schwa, it does so as a side-effect of schwa's prosodic status: schwa is non-moraic. So, there are no sonority-driven stress systems which are motivated by constraints that refer to a *direct* connection between feet and sonority levels. Instead, all sonority-driven stress is due to the distribution of non-moraic schwa and how this interacts with foot structure. The phonetic prediction is that whenever schwa is

avoided in stress systems, it should have the acoustic characteristics of non-moraic schwa, as mentioned in section 1.2.2 above.

1.4 Outline of the case studies

A central claim of this dissertation is that there are non-moraic and moraic schwas. Furthermore, they can coexist in the same grammar. I will argue that evidence from Piuma Paiwan supports this claim. Moreover, the proposed theory predicts that stress assignment is never influenced by vowel sonority. I will provide evidence from Gujarati, together with Piuma Paiwan, that stress assignment is immune to vowel sonority.

Chapter 3 argues that moraic and non-moraic schwa can co-exist in Piuma Paiwan, an Austronesian language that has been reported to have sonority-sensitive stress (Chen 2009a, b, Yeh 2011). All descriptions agree that stress avoids the lowest sonority vowel – schwa – when there is a more sonorous one in the final syllable: [kərí] 'small' cf. [káka] 'sibling'. Surprisingly, stress also moves away from a penultimate schwa when the final syllable also contains schwa: [[əʎə́t] 'lip'. I will show that although there is objective acoustic evidence that stress avoids landing on a schwa, such avoidance is actually a side-effect of schwa's prosodic status: schwa is usually non-moraic in Piuma Paiwan. However, under certain foot-related conditions, schwa is required to have moras. Strikingly, schwa is required to be monomoraic when in the non-head position of a foot, and bimoraic when it is in the head syllable of a foot. The result is that Piuma Paiwan has *three* types of schwa: bimoraic [əː], monomoraic [ə], and nonmoraic [ᵊ]. The different kinds of schwa have significantly distinct acoustic effects, particularly in duration and vowel quality variability.

When schwa lacks a mora, it is phonetically realized as extremely short, and its height and backness are highly influenced by surrounding segments.

Chapter 4 presents evidence against the existence of sonority-driven stress in Gujarati. Gujarati is one of the clearest and most revealing cases of sonority-driven stress with distinctions among peripheral vowels (de Lacy 2004). A production experiment was performed to determine the accuracy of the claim that [a] attracts stress away from the default position (Cardona 1965, Mistry 1997, de Lacy 2002, Cardona & Suthar 2003, Doctor 2004, Schiering & van der Hulst 2010). Specifically, stress is attracted away from the default penultimate position if there is an [a] elsewhere: [ʃikár] 'a hunt' cf. [dʒája] 'let's go' (data from de Lacy 2002). Of the five types of phonetic evidence examined, only F1 provides clear evidence for stress, revealing stress to be consistently penultimate, and not sonority-driven. In short, the results from Gujarati support the claim that stress assignment is not influenced by peripheral vowels.

Chapter 5 provides an extensive typological survey of languages reported to have sonority-driven stress. I will offer a survey of languages with peripheral distinctions, and languages reported to avoid central vowels (mostly schwa). Crucially, I will show that most of the descriptions are impressionistic and without phonetic or phonological evidence to support the described metrical structure. Even for descriptions providing potential evidence for stress, I will argue that they are either weak or not relevant to the metrical structure. Finally, I will present a factorial typology and demonstrate that many sonority-driven stress systems can be generated by constraints that do not refer to vowel sonority.

CHAPTER 2

THEORY

2.1 Introduction

The goal of this chapter is to describe the phonological and phonetic theory proposed in this dissertation, and discuss what constitutes potential evidence for the theory.

The core of the theory is that syllables that contain a non-moraic schwa are possible in phonological outputs, such as those shown below:

(1)   Syllables with non-moraic schwa
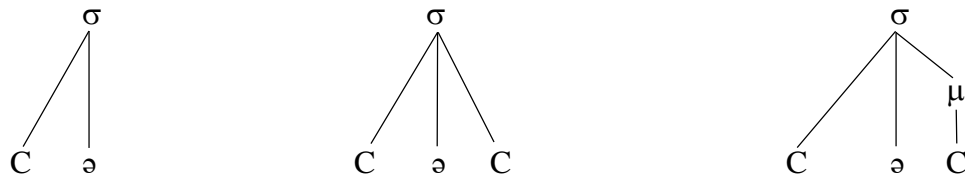
Such syllables arise through a pressure for schwa to be non-moraic, expressed as the constraint $*\mu/\partial$ – one of a family of constraints that regulates the sonority of syllable nuclei. Antagonostic to this constraint are requirements that syllables have moras – both directly and indirectly.

The theory further advances the following restriction on markedness constraints:

(2)   Hierarchical Locality restriction on markedness constraints

If a markedness constraint mentions prosodic node *p*, it may mention nodes at *p-1* and *p-2*, but not nodes at other levels.

The Hierarchical Locality restriction, building on Itô & Mester (2003), means that there can be no constraints like *HD$_{Ft}$/ə, which is violated when a schwa appears in the head mora of the head syllable of the head foot. As such, certain kinds of sonority-driven systems are predicted to be impossible (contra Kenstowicz 1997, de Lacy 2002 et seq.).

Section 2.2 proposes the representation of non-moraic and moraic schwa, and discusses the constraints that motivate them. Section 2.3 proposes phonetic properties of non-moraic and moraic schwa. Section 2.4 reviews phonological and phonetic evidence for metrical structure, while section 2.5 reviews the history of non-moraic schwa.

2.2 Phonological proposals

This section consists of two parts. Section 2.2.1 proposes the phonological representation of non-moraic and moraic schwa. Section 2.2.2 discusses constraints motivating non-moraic and moraic schwa in Optimality Theory.

2.2.1 Representation

In accord with previous proposals, I propose that schwa can be non-moraic (Kager 1989, 1990, Féry 1995, 1996, Crosswhite 1999, and others – see below). In this way, it behaves in the same way as high vowels, which have non-moraic counterparts (Hyman 1985, Hayes 1989, and many others). For example, in (3), the high vowel /i/ surfaces as a glides [j], while /u/ surfaces as [u] because it is attached to a mora.

(3)   High vowels and glides in moraic theory

```
            σ
           /|
          / μ
         /  |
        i   u
         [ju]
```
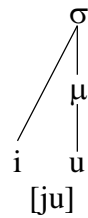
In this dissertation, moraic schwa is written as [ə], while non-moraic schwa is represented as [ᵊ].

Just like non-moraic [j] and [w], [ᵊ] can can occupy syllable onsets and non-moraic codas, as represented below with the syllables [pᵊi] in (4a) and [piᵊ] in (4b).

(4)   Non-moraic schwas in syllable margins

a.
```
            σ
          //|
         // μ
        ///  |
        p ə  i
```

b.
```
            σ
           /|\
          / μ \
         /  |  \
        p   i   ə
```

Non-moraic schwas in syllable margins produce rising and falling light (i.e. monomoraic) diphthongs. However, diphthongs are not the focus of this dissertation, so I will focus on non-moraic schwa's role in syllable nuclei.

I propose that schwa is special because it is always [+vocalic], even when it is non-moraic. This contrasts with the glides [j] and [w] which are [−vocalic]. The [+vocalic] feature of schwa allows it to head syllables without a mora. Of course, like other vowels, schwa may bear moras – either one or two. So, the following three syllable structures are possible:

(5)   Syllables with schwa
       a. Minor/defective syllable   b. Monomoraic schwa   c. Bimoraic schwa
       with nonmoraic schwa

$$\begin{array}{ccc}
\sigma & \sigma & \sigma \\
\end{array}$$

[C°]   [Cə]   [Cə:]
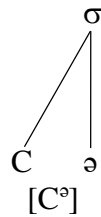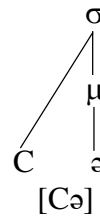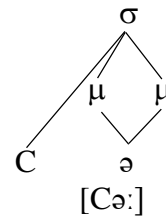
The representation in (5a) is the same as that of minor (or 'defective') syllables (Matteson 1965, Lin 1993, 1997, 1998, Shaw 1994, Gafos 1998, and many others), and has also been proposed to account for weightless or reduced vowels (e.g. Crosswhite 1999 and others). In this dissertation, I will make the restrictive assumption that *only* schwa can appear in structures like (5a) because it is uniquely a [+vocalic] non-moraic segment. In other words, every syllable must contain either a mora or a vocalic segment. So, as an example, there are no minor syllables with the form [pj], where [j] is a nonmoraic high vowel. Minor syllables are discussed further below. From now on, the representation in (5a) will be called 'minor syllable schwa'.

Importantly, the moraicity of schwa is not a parametric choice – I propose that non-moraic, monomoraic, and bimoraic schwas can co-exist in the same phonological system. Chapter 3 will present evidence from Piuma Paiwan that shows that while schwa is usually non-moraic in that language, it is monomoraic when it is in the non-head position of a foot, and bimoraic when it is forced to be in the head syllable of a foot.

We will see below in the discussion of constraints that three types of language can arise with regard to minor syllable schwas. First, a language may only allow non-moraic schwas. Second, a language may require schwa to be moraic. Third, a language may have a mixed combination: non-moraic and moraic schwas co-exist in the same phonological

system. As I will show in chapter 5, Chuvash is a potential candidate for the non-moraic schwa system, and Eastern Armenian for the moraic schwa system. Lastly, chapter 3 presents evidence that Piuma Paiwan has a mixed system. An extensive typological survey is provided in chapter 5.

2.2.2 Computation

The second part of the proposal is the computational mechanism that forms minor syllable schwas. In general terms, the existence of minor syllable schwa is due to conflicting phonological pressures.

There is pressure against schwa having a mora: that is the general pressure for lower sonority elements to not bear moras. In Optimality Theory, this pressure has been expressed through constraints on syllable nuclei and sonority levels (Prince & Smolensky 1993/2004), or through constraints on moras and sonority levels (Zec 2007: 180). In Zec (2007)'s proposal, obstruents are the least desirable segment to bear a mora, whereas vowels are the most favored segment to carry a mora.

(6)   Constraints on moraicity, in a fixed ranking (Zec 2007: 180)

        *μ/Obstruent »» *μ/Nasal »» *μ/Liquid »» *μ/Vowel

Zec (2007) mainly deals with the distribution of consonants in nucleus and coda position. The vocalic portion of the sonority hierarchy from (de Lacy 2006) is given in (7). As in de Lacy (2006) and many others, the label 'i/u' stands for 'the sonority category of high peripheral vowels' (i.e. [i y ɯ u]), and so on for 'e/o' and 'a'.

(7)   Vocalic portion of the sonority hierarchy (de Lacy 2006: 68)

low		mid		high		mid		high
vowels	⟩	peripheral	⟩	peripheral	⟩	central	⟩	central
		vowels		vowels		vowels		vowels
'a'		'e/o'		'i/u'		'ə'		'ɨ'

I adopt the moraic model of the syllable here, and so the constraints below are expressed in moraic terms. I also adopt the method of expressing hierarchies from de Lacy (2006) – i.e. through stringent constraint form instead of a fixed hierarchy.

(8)   Constraints on moras and sonority levels (after Zec 2007, also see Prince &
       Smolensky 2004)

       *μ/ə "Incur a violation for every schwa that bears a mora."

       (From the family of constraints *μ/ə, *μ/{ə,i/u}, *μ/{ə,i/u,e/o}, *μ/{ə,i/u,e/o,a})

The set of constraints in (8), while banning all vowels from nuclear position, places the strongest ban on the least sonorous vowel schwa and the weakest on low vowels. In other words, schwa is the least desirable mora-bearing segment.

The constraint *μ/ə is plausibly phonetically grounded (e.g. Gordon 2007). The existence of *μ/ə could be attributed to schwa's minimal demands on articulatory movement, so allowing it to be briefer than other vowels. Specifically, the tongue position associated with mid-central vowels like schwa is closer to its default location in the center

of the vocal tract. Thus, schwa requires less movement of the tongue, and presumably less articulatory effort, than their more peripheral counterparts requiring vertical or horizontal movement of the tongue and jaw (Gordon 2012). In contrast, moras are durational units, suggesting a conflict between the inherent duration-lending property of moras and the duration-minimizing nature of schwa. As a consequence, schwa is too short to be moraic. However, this suggestion is pure conjecture; it is equally possible that *μ/ə is innate, and simply part of an abstract (or at least synchronically abstract) condition on moras and vowel types.

I do not address the issue of how high central vowels fare in these constraints. I have found very little evidence for their status (though see chapter 5 for discussion). There are also constraints against having consonants in moras – moraic consonants are even more marked than moraic schwa, as discussed in Zec (2007) and Prince & Smolensky (1993/2004). I do not discuss these constraints here to keep the discussion focused on schwa.

The other important issue about these constraints is the type of μ involved: i.e. the head mora (nucleus) of the syllable vs. the non-head mora (i.e. a coda mora, or mora that dominates the second member of a diphthong). Throughout the following chapters, the relevant mora will be the nuclear mora – i.e. the head μ of the syllable. I leave the issue of constraints on non-head moras and [ə] to future work.

The constraints above are somewhat different from the approach taken by Crosswhite (1999) (C99). C99: 75's proposal is that there are constraints against *non-moraic* segments: e.g. *NONMORAIC/−HIGH "Nonmoraic vowels may not have a sonority greater than that of i,u.". With the *μ/ə constraint, it is not clear that the

*NONMORAIC/−HIGH constraint is necessary. It is quite possible that they co-exist: after all *μ/ə is a constraint about syllable nuclei, whereas *NONMORAIC/−HIGH is a constraint about syllable margins, and may simply express the markedness generalization that high sonority margins are undesirable. For this dissertation, the primary motivation for schwa moralessness will be taken to be *μ/ə – i.e. low sonority moraic segments are undesirable.

The constraint *μ/ə can drive schwas to be non-moraic when appropriately ranked. There are many constraints that oppose *μ/ə, however. One family of constraints relates to *headedness* – the requirement that every prosodic node at level *n* must dominate at least one node at level *n*−1 (Selkirk 1981, 1984, 1995, Nespor & Vogel 1986). The general HEADEDNESS constraint schema is given below, along with two instances that will prove particularly significant in the following chapters.

(9)   Constraints on headedness (Selkirk 1981, 1984, 1995, Nespor & Vogel 1986)

a. HEADEDNESS schema:

"Incur a violation for any node *n* s.t. *n* does not dominate some node *m* where *n* is on layer *i* and *m* is on layer *i-1*."

b. HEADEDNESSFT "Incur a violation for any foot that does not dominate a σ."

c. HEADEDNESSσ "Incur a violation for any σ that does not dominate a μ."

HEADEDNESS-σ requires each σ node to dominate at least one mora. This constraint will be abbreviated to HD-σ below.

HD-σ conflicts with *μ/ə when [ə] is the only available (or most eligible) segment. The following tableau illustrates this conflict.

(10)   Conflict between *μ/ə and HD-σ

/tə/	*μ/ə	HD-σ
☞ a. tᵊ		*
b. tə	*!	

In the tableau above, candidate (10a) consists of a syllable with a [t] onset and a non-moraic

schwa, while candidate (10b) consists of a [t] onset and a moraic schwa. For the sake of

clarity, the two candidates are represented in full below:

(11)   Candidates in tableau (10)
        Candidate (10a): Minor syllable schwa   Candidate (10b): Monomoraic schwa
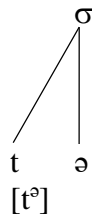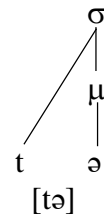
Candidate (10a) violates HEADEDNESS-σ (HD-σ) because it contains a σ node that does not

dominate a μ. In contrast, candidate (10b) violates *μ/ə because it has a mora that

dominates a schwa. It is clear that if *μ/ə dominated HD-σ, candidate (10a) would win and

the grammar would produce non-moraic schwas. If HD-σ dominated *μ/ə, on the other

hand, candidate (10b) would win and the grammar would produce moraic schwas.

● *Other constraints that are violated by non-moraic schwa*

HD-σ is not the only constraint that is violated by non-moraic schwa. In fact, the majority

of the discussion in chapters 3, 4, and 5 will be about metrical systems and how non-moraic

schwa relates to foot structure. As an example, an important foot-related constraint that can force schwa to be moraic is given below.

(12)   Constraint on foot content

FᴛBɪɴμ "Incur a violation for every Ft node that does not dominate two and only two moras." (after Élias-Ulloa 2006)

As a note on foot structure and candidates, Itô & Mester (2003) claim that Strict Layering holds true at the lowest prosodic levels of moras and syllables. I adopt their assumption that moras can only exist as parts of syllables, as in (13).

(13)   Mora Confinement: μ is licensed only by σ (Itô & Mester 2003: 11).

The restriction above means that candidates cannot contain a Ft node that directly dominates a μ node, so such candidates will not be considered below. However, a σ node can dominate a root node directly, as in the minor syllable schwa structure identified above.

The importance of constraints like FᴛBɪɴμ is that they do not require schwa to be moraic in every environment. For example, in the tableau below, schwa is generally non-moraic (due to having *μ/ə outrank Hᴅ-σ. However, when feet must be bimoraic, schwa is forced to bear a mora.

(14)   Ranking for mixed system

/patəkə/	FTBINµ	*µ/ə	HD-σ
a. (pá.tˀ)kˀ	*!		**
☞ b. (pá.tə)kˀ		*	*
c. (pá.tə)kə		**!	

As a reminder, [ə] bears a mora while [ˀ] does not; [a] also bears a mora. Candidate (14a) violates FTBINµ because its foot contains only one mora – i.e. the [a]'s. Candidate (14c) avoids violations of FTBINµ by having moraic schwas, but at the cost of multiple violations of *µ/ə. Candidate (14b) wins because it has a bimoraic foot – due to the leftmost schwa being moraic – but otherwise has non-moraic schwas. In this way, we can see how a grammar with both moraic and non-moraic schwa can come about. An example of such a language is given in chapter 3.

In general, then, three schwa systems can be generated by the constraints on moraicity (i.e. *µ/ə), headedness (i.e. HEADEDNESSσ), and any mora-demanding constraints (e.g. FTBINµ). That is, for a given phonological system, it is possible that (i) schwa is always moraless, (ii) schwa is always moraic, or that (iii) moraic and non-moraic schwas co-exist. For evidence for each system, see the typological survey in chapter 5.

(15)   Basic ranking schemas

- ℂ is a constraint that requires moraic schwa in some environments

a. *µ/ə » HD-σ, ℂ   Schwa is always moraless.

b. ℂ » *µ/ə » HD-σ   Moraic and non-moraic schwa co-exist.

c. HD-σ » *µ/ə   Schwa is always moraic (ℂ's ranking is not crucial).

The basic 'moraless schwa' ranking is illustrated below with the same candidates as above. Essentially, moraic schwa is prohibited because the constraint *μ/ə dominates HD-σ.

(16)   Ranking for non-moraic schwa in all environments

/patəkə/	*μ/ə	HD-σ	FTBINμ
☞ a. (pá.tˀ)kˀ		**	*
b. (pá.tə)kˀ	*!	*	
c. (pá.tə)kə	*!*		

In contrast, moraic schwa is motived by ranking HEADEDNESSσ over *μ/ə. For every schwa that is non-moraic in the output, it incurs one violation of the constraint HEADEDNESSσ. So, candidates (17a) and (17b) are eliminated because not every schwa is moraic. The optimal output is (17a) due to the fact that the two schwas are moraic. The ranking for FTBINμ is not crucial here as the ranking HEADEDNESSσ » *μ/ə ensures every schwa to be moraic in the output. In other words, schwa is always moraic under the constraint ranking.

(17)   Ranking for moraic schwa

/patəkə/	HD-σ	*μ/ə
a. (pá.tˀ)kˀ	*!*	
b. (pá.tə)kˀ	*!	*
☞ c. (pá.tə)kə		**

An extensive factorial typology with relevant constraints will be provided in chapter 5.

• *Schwa in the input*

One important issue is the status of schwa in the input. I have not found any evidence that any language *contrasts* moraic and non-moraic schwa in the output: while there are

languages that can have both moraic and non-moraic schwa in different environments (see chapter 3), I have not found any languages where the moraicity of schwa is unpredictable in the same environment. Such a language would have distinct words like [tátə] and [tátᵊ].

I should note that Hyman (1985) suggests that schwa can be contrastively 'weight-bearing' or 'non-weight-bearing'. It is possible that this distinction requires a formal implementation in terms of moraicity. However, I have not found clear evidence in the phonological and phonetic descriptions of Chuvash to support such a contrast (see ch.5 for further discussion).

The lack of contrastive moraic and non-moraic schwa can be handled by either restricting the input or the constraints. In terms of input restrictions, it may be that schwa is never underlyingly marked for moraicity. Alternatively, there may be no constraints that preserve underlying moraicity on schwas. Either option would produce the desired result.

Schwa is not alone in not having contrastive moraicity. It is possible that no other vowels are contrastively moraic, either. Specifically, it is not clear whether there are languages that contrast glides and their high vowel counterparts (Ellen Kaisse, p.c.). I leave the issue of whether contrastive moraicity is necessary to future work. In the rest of this dissertation, input schwa will be represented as /ə/, without any commitment to whether it is mora-bearing or not.

• *Prosody is myopic*

So far, the proposals made above have been essentially reductionist: I have not proposed new constraints, but rather reaffirmed the importance of existing constraints on moraicity and prosodic form. While I have adopted the non-standard representational idea that

certain syllables may lack moras, there is ample precedent for such a proposal in the literarature (see section 2.5 for more details).

However, I wish to go further in proposing that certain types of constraint *do not* exist. The general proposal is that prosody is myopic. That is, markedness constraints that mention prosodic structure are limited as to which prosodic elements they can mention. Specifically, I will argue that stress does not have access to vowel sonority, consistent with Itô & Mester (2003)'s proposal on hierarchical locality. Itô & Mester (2003) argue that prosodic structures are subject to a locality condition, as in (18).

(18)   Hierarchical Locality (Itô & Mester 2003)

A condition operating at prosodic level C_i has access only to structural information at C_i and at the subjacent level C_{i-1}.

That is, within any given domain only the immediate internal structure of the subjacent domain can be accessed. I propose that this condition can be expressed in terms of markedness constraints as follows:

(19)   Hierarchical Locality restriction on markedness constraints

If a markedness constraint mentions prosodic node *p*, it may mention nodes at *p-1* and *p-2*, but no nodes at other levels.

So, FTBINµ is a possible constraint because it refers to the Ft node and µ nodes, where the µ is 2 levels below Ft. However, constraints that mention the Ft node cannot refer to root

nodes, or features at the root node level: i.e. there can be no constraints of the form *Ft/*x* where *x* is a root node structure or root-node feature. For example, sonority is arguably not a subsegmental feature – it behaves like manner features, which McCarthy (1988) proposes inhabit the root node. In our theory, then, stress only has access to the levels of σ and μ in the prosodic hierarchy (and crucially *not* to the root node level).

The practical implication of the Hierarchical Locality restriction is that constraints like *Ft/ə cannot exist (cf. Kenstowicz 1997, de Lacy 2002 et seq.). This constraint, expressed more fully, bans a root node with the sonority level of 'ə' in the head mora of the head syllable of a foot. The constraint mentions prosodic nodes that are three levels apart – Ft and root node – and so cannot exist.

The empirical evidence for myopic prosody comes from my experiments and fieldwork on Gujarati and Piuma Paiwan, both of which are claimed to have a particular type of 'sonority-driven stress'. In such systems, foot heads are claimed to avoid segments with particular sonority values. However, Hiererchical Locality prevents such sensitivity from existing.

On the other hand, the present theory *does* predict that feet can have a limited sensitivity to sonority – through moraic structure. If schwa is non-moraic, then it cannot be the head of a foot, and so stress will avoid schwa. So, the theory predicts that metrical systems should exist that avoid schwa, but only because of its non-moraic status. The theory further predicts that there can be no other kind of sonority-sensitive system: there can be no system where stress avoids high vowels, or mid vowels, or any other sonority category.

Chapter 3 will show how feet avoid schwa through its lack of a mora. Chapter 4 will examine a case of purported non-schwa sonority-driven stress – Gujarati. I will show that there is no evidence that the language has foot structure that is sensitive to non-peripheral vowel distinctions.

2.3 Phonetic proposals

The previous section makes specific claims about schwa: i.e. that it can be either moraic or non-moraic. This section proposes that schwa's moraicity is detectable via duration and vowel quality variance.

It has been noted in many studies that syllables containing schwa are phonetically distinct from syllables containing full vowels. For example, Swedish schwa vowels are characterized by lower amplitude and shorter duration than full vowels (Lindblom 1963). However, much less attention has been devoted to identifying the phonetic characteristics of schwa vowels themselves, as noted by Flemming (2009).

Here I propose that the different kinds of schwa have significantly distinct acoustic effects, particularly in duration and vowel quality variability. In terms of duration, I echo Crosswhite (1999: section 7.1.0 to a great extent). To summarize:

(20)   Phonetic properties of schwa

      a. Moraless schwa has minimal duration; large vowel quality variance.

      b. Moraic schwa has longer duration; small vowel quality variance.

      c. Bimoraic schwa has even longer duration; small vowel quality variance.

Moraic quantity determines duration (Hubbard 1995, Broselow *et al.* 1997). So, schwa's duration is determined based on the number of moras. Here, I propose that bimoraic schwa is perceptually distinctively longer than monomoraic and non-moraic schwas, and monomoraic schwa is then perceptually distinctively longer than non-moraic schwa. Crucially, since non-moraic schwa has no mora at all, it has minimal duration. 'Minimal' duration here means intrinsic duration – i.e. only the duration that schwa needs to be produced so that it may be perceived. The exact millisecond value of minimal duration will depend on an individual's articulators (i.e. their speed of articulatory movement). In the subjects' speech reported in chapter 3 and 4, non-moraic schwa often had durations of around 40-50ms, which was far shorter than durations for non-schwa vowels.

In contrast, mono-moraic schwas have durations that are similar to other full vowels. For example, for speakers of Piuma Paiwan in chapter 3, moraic schwa had a mean duration of 70-80ms, which is relatively far longer than the 40-50ms of non-moraic schwas. Certainly, monomoraic schwa was shorter than other full vowels; for example, monomoraic [u]'s mean duration was around 115ms. However, this difference can be ascribed to articulatory differences – i.e. [u] requires more significant articulator movement than [ə], and the length of [u] reflects the extra time it takes for the articulators to get into position to produce a [u].

Bimoraic schwa is much longer than monomoraic schwa. For example, for the Paiwan speakers reported in chapter 3, bimoraic schwas were over 130ms long (compared to the monomoraic schwas' 70-80ms). Again, bimoraic schwa is shorter than other bimoraic vowels – e.g. bimoraic [u] was over 200ms long. Again, such a difference is due

to the different inherent durations of [u] and [ə], determined by their different articulatory requirements.

Crosswhite (1999: section 7.1.0) (hereafter C99) characterizes the duration differences of non-moraic vs. moraic segments in terms of duration windows. C99: 171 proposes that monomoraic vowels must have a lower durational bound of 40ms – the minimum needed to perceive the presence of a vowel, whereas non-moraic vowels have a lower bound of 0ms. In contrast, I suggest that if a vowel has a duration of 0ms it is not phonologically present, or has been reduced by auxiliary phonetic processes that reduce duration (e.g. polysyllabic shortening). Non-moraic schwa duration must be enough to be perceptible – i.e. for the hearer to perceive that *some segment* is present (though not necessarily distinctly as a *vowel* – it may be perceived as extra aspiration or breathiness, for example). For the speakers of Piuma Paiwan reported in chapter 3, such schwas were around 40-50ms in duration. Mono-moraic schwas are expected here to have durations similar to mono-moraic full vowels, except that they will in general be shorter due to the lesser articulatory movement demands placed on them: because schwas on average require less movement to reach their articulatory target, they will be shorter than other vowels.

The theory predicts that if any duration pattern is found that does not follow the moraic content just described, the duration observed will not be moraic duration, but due to some other duration-extending phonological or phonetic process (e.g. phrase-final lengthening). After all, there are many phonological and phonetic influences on duration – headedness/stress, the voicing of following consonants, phrase-final lengthening, polysyllabic shortening, focal lengthening, and many others. These are discussed at length in chapter 3.

Second, I propose that non-moraic schwas have greater variation in quality (F1 and F2) compared to moraic schwas. Several studies have noted that the quality of schwa is profoundly affected by the acoustic and articulatory properties of neighboring environments (e.g. Browman & Goldstein 1992, Koopmans-van Beinum 1994, Flemming & Johnson 2007, Flemming 2009). Van Oostendrop (2000) interprets this characteristic as evidence for the placelessness of schwa. However, duration can also account for variation in vowel quality (Lindblom 1990). Specifically, articulatory targets may not be fully reached because there is insufficient time for articulatory movement. Since non-moraic schwa is significantly shorter than moraic schwa, non-moraic schwa therefore has less time for articulatory movement than moraic schwa. So, non-moraic schwa is predicted to show greater vowel quality variance than moraic schwa. Thus, variation in vowel quality, or phonetic undershoot, can be viewed as a phonetic property that is parasitic on duration.

In summary, I have proposed that duration and vowel quality variance can be used to detect the moraicity of schwa, modulo other effects on duration. Chapter 3 shows how the phonetic properties mentioned above provide evidence for non-moraic, monomoraic, and bimoraic schwas in Piuma Paiwan.

2.4 Evidence for metrical structure

To prove the validity of the proposed theory here, solid phonological or phonetic evidence is required. Below I review relevant phonological and phonetic evidence for metrical structure, as the central focus here is on the word-level stress in Piuma Paiwan and Gujarati.

A modular view of the phonological and phonetic components is adopted here (e.g. Keating 1985, Cohn 1998). The phonological output has metrical structure specified, such as PrWd and foot head syllables and non-head syllables of feet.

Many phonological and morpho-phonological processes are potentially sensitive to heads. Typical stress-sensitive phonological processes include vowel reduction (e.g. Crosswhite 2004), fortition (e.g. Bye & de Lacy 2008), and allophony (e.g. Beckman 1998). Stress-sensitive morphological processes such as infixation (e.g. McCarthy 1982 on English expletive infixation), allomorphy (e.g. Kager 1996), and truncation (e.g. Benua 1995) are also found.

The phonetic module can realize heads and non-heads in a variety of ways (Gordon & Roettger 2017). Stressed vowels can be realized with an excursion in fundamental frequency (F0), increased intensity, and increased duration. Examples are found in a diverse set of languages, such as English (Fry 1955, 1958), Polish (Jassem *et al.* 1968), Chickasaw (Gordon 2004), Turkish (Levi 2005), and Kabardian (Gordon & Applebaum 2010). Other potential acoustic correlates of stress have come to light, such as vocalic peripheralization (or centralization of unstressed vowels) (Campbell & Beckman 1997, Gordon 2004), and lack of spectral tilt (Sluijter & van Heuven 1996).

The reports cited above indicate that there are a variety of different acoustic effects of stress, but not all cues are always used in every language. Gordon & Roettger (2017) conducted a cross-linguistic survey of acoustic correlates of word stress. They conducted a survey of 110 studies of 75 languages and find that a large number of parameters potentially signal stress, including duration, fundamental frequency (F0), intensity, vowel quality (F1 and F2), and spectral tilt. Crucially, they found that studies vary considerably

in which subset of these potential stress correlates are examined, making it difficult to establish which ones are the most consistent cues to stress. They also emphasize the importance of methodology, as carefully evaluating experimental design choices and statistical analyses can genuinely tell us about the phonetic manifestation of word stress (see Roettger & Gordon 2017).

As I will show in chapters 3 and 4, previous descriptions of metrical structure in Piuma Paiwan and Gujarati rely heavily on the grammar authors' perception – i.e. they are impressionistic. Of phonological evidence, only stress-sensitive allophony is mentioned in the descriptions of Gujarati. So, one of the goals of those chapters is to provide robust phonological and/or phonetic evidence of metrical structure. For example, chapter 3 identifies evidence of foot head location through characteristics of duration and F0.

2.5 History of non-moraic schwa

As mentioned above, the theory presented here makes use of well-established constraints – those on moras and sonority, and those on prosodic structure (particularly headedness). The major non-standard aspect of the current proposal is the idea that there can be non-moraic schwa syllables: i.e. a syllable that contains a schwa that does not bear a mora, repeated below.

(21)   Minor syllable schwa

Such a representation is not part of the original conception of the Prosodic Hierarchy, which assumed that headedness was inviolable (Selkirk 1981, 1984, Nespor & Vogel 1986, though cf. Selkirk 1995). However, there have been a number of arguments that schwa can be non-moraic. I review them in this section.

One of the earliest proposals that vowels may be non-moraic is found in Hyman (1985)'s analysis of Chuvash and Mari, with particular focus on their stress systems. The proposal there is that vowels project σ nodes directly, without projecting moras. In a sense, then, vowels can be syllabic without being moraic – they can form the nucleus of a syllable yet not be mora-bearing.

In the present theory, if a foot head avoids landing on a schwa, it can only be due to schwa's non-moracity. In the specific case of Chuvash, I argue in chapter 5 that phonetic evidence indicates that schwas are *always* non-moraic, even when they are the only vowels in a word.

In a number of respects, Crosswhite (1999: ch.7) provides the most extensive phonological and phonetic proposals about non-moraic schwa and non-moraic vowels more generally. The phonetic proposals about duration in section 2.3 above are particularly endebted to Crosswhite (1999)'s proposals. In fact, Crosswhite (1999: ch.7) provides an extensive defense of the idea that vowels can be non-moraic. The present work can be seen as an extension of Crosswhite (1999)'s proposal, with particular focus on sonority-driven stress.

Crosswhite (1999) (hereafter C99) provides extensive arguments that Russian dialects involve moraic and non-moraic vowels. Specifically, unfooted vowels end up

being non-moraic, and so undergo extensive reduction (see C99: ch.3). In contrast, footed vowels surface with moras. I will show that this kind of pattern is also found in Piuma Paiwan: [ə]'s in feet are always moraic (or bimoraic), but are non-moraic outside feet. A more general analysis of such cases is provided in chapter 5. However, whether Russian involves phonological vowel reduction in certain environments is a controversial issue: see Barnes (2006, 2007), and Iosad (2012).

Crosswhite (1999) identifies a number of other languages as having non-moraic schwa. For example, post-tonic vowels in Brazilian Portuguese are argued to be non-moraic (C99: 55), and similar arguments are made for European Portuguese (C99: 103).

Differences between types of schwa have been observed before, though not necessarily put in terms of moraicity. For example, van Oostendorp (1995, 1998, 2000) (hereafter O) has argued that there are three kinds of schwa in Dutch, called 'r-schwa', 'e-schwa', and 'u-schwa'. 'R-schwa' alternates with full vowels in vowel reduction, 'e-schwa' alternates with zero in certain consonant clusters, and 'u-schwa' almost never alternates. Essentially, O argues that schwa has only one feature [−cons], which is one of the major class features specified on the root node (McCarthy 1988). It therefore is a very defective type of vowel, and it heads a very defective type of syllable.

All three types of schwa avoid stress (O 2000: 132). In terms of the present theory, this indicates that they all prefer to be non-moraic whenever possible. However, O identifies many differences in phonological behavior between the three schwa types. In general, most (if not all) r-schwas are underlying, while e-schwas are inserted. R-schwas are derived from full vowels by vowel reduction, but vowel reduction cannot apply in all environments. For example, vowels do not reduce initially, even when unstressed (O 2000:

138). In terms of the present theory, this suggests that there is a ban on word-initial non-moraic schwa. There are a great many more subtleties with Dutch schwa that require further investigation.

O develops a Projection Theory to account for different kinds of schwa. Specifically, he argues that there are constraints of the following types: (i) if a segment dominates a feature F, it should head a branching constituent of type T, and (ii) if a segment heads a branching constituent of type T, it should dominate a feature F. These bidirectional constraints are called *projection constraints*.

Reduction schwa is accounted for by the constraint PROJECT(V, FT), which requires that vowels with vocalic features (V) occur in the heads of feet. If a vowel with vocalic features appears in the non-head position of a foot, it violates the constraint PROJECT(V, FT)[1]. So, an output like [(CV́.CV)] violates the constraint because the second full vowel is not the head of the foot. Instead, [(CV́.Cə)] incurs no violation of the constraint. On the other hand, epenthetic schwa is due to the constraint PROJECT(σ, −cons), which requires syllables to have at least a vocalic root in their head. For syllables with no underlying vowel, insertion of schwa is the most economical way since schwa is exactly a [−cons] root. Finally, the constraint PROJECT(−cons, σ) forces underlying schwa to surface, even though O (2000: 169) claims that underlying schwa in many cases is blocked from surfacing. The constraint requires a segment that has a [−consonantal] root to occur in the head of a syllable. In short, O's analysis relies on the featural representation of schwa and the

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[1] There is a more restricted version of the constraint: PROJECT(V, FT$_2$). That is, full vowels occur in the in the heads of branching feet. See van Oostendorp (2000: 149-150) for discussion.

projection relationship between features and prosodic structures. It is thus different from the moraic approach proposed above.

However, O's theory will not be adopted here. I will show that schwa can be stressed and unstressed in Piuma Paiwan (see chapter 3). To characterize the distinction between stressed and unstressed schwas, O's theory has to postulate two kinds of schwa with different segmental features, because schwa with a [−cons] root only accounts for the appearance of unstressed schwa. Moreover, it is observed that there is a three-way durational distinction between schwas. O's theory provides no explanation for the differences in duration between the three kinds of schwa. In moraic theory, moraic quantity determines duration (e.g. Hubbard 1995, Broselow *et al*. 1997). It is reasonable to model the stressibility and durational difference in terms of moraic content: long schwa has two moras, short schwa has one mora, and the 'overshort' schwa has no moras at all.

There have also been proposals that schwa is transiently moraless. For example, Kager (1989, 1990) argues that weightless vowels cannot head a syllable in initial syllabification, so they are necessarily stressless. This creates a three-way moraic distinction in Dutch vowels. That is, short vowels are lexically monomoraic, whereas long vowels and diphthongs are bimoriac. Most importantly, schwa is moraless, and so it forces stress onto the immediately preceding syllable. However, schwa is only moraless at Level 1, as Kager assumes that initial syllabification, word-stress assignment, and other processes take place at this early stage. Schwa acquires a mora at Level 2, because resyllabification takes places at this level. In other words, schwa is invisible at Level 1, and is syllabified at Level 2. It follows that schwa cannot receive stress.

Stress in Dutch is both bounded and quantity-sensitive (Kager 1989). If the penultimate syllable is closed, it is stressed. If the penultimate syllable is open, stress is either on the penultimate or on the antepenultimate syllable. When a schwa appears in the penult, stress falls on the antepenultimate syllable (Kager 1990: 253), as in [hέ.ŋə.lo]. The derivation from Kager (1990) is provided in (22). The velar fricative /x/ is deleted in syllable-final position.

(22)   Non-final schwa in Dutch
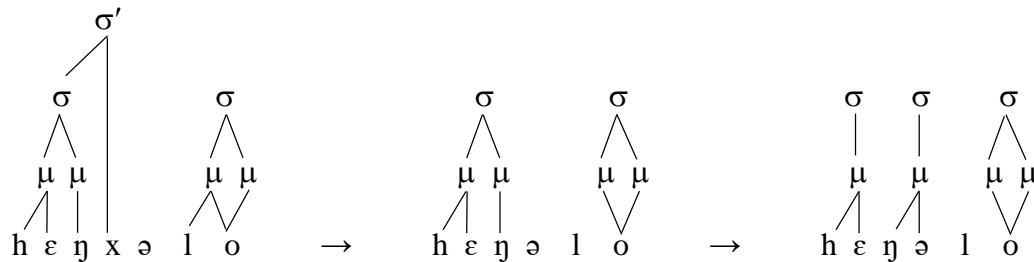
Since schwa is moraless at Level 1, it cannot receive stress at this stage. It becomes monomoraic at Level 2 due to resyllabification. As a result, stress falls on the antepenultimate syllable.

Similarly, Féry (1995, 1996) argues that schwa in German is moraless, so it is never stressed (also see Kehoe & Lleó 2003). Syllables in German can be non-moraic, bimoraic, and trimoraic. Specifically, syllables with a schwa or a syllabic sonorant in their nucleus are non-moraic, as [gl̩] in [foː.gl̩] 'bird', and [tə] in [ʀa.tə] 'rat'. Open syllables with a tense vowel or closed syllables with a lax vowel and closing consonant are bimoraic, as [ʀɔ] in [ʀɔ.bə] 'seal', and [mʏl] 'garbage'. The same syllables plus an additional consonant are trimoraic: the third mora does not belong to the core syllable, but contributes to the weight calculation, as [dɛnt] in [ʃtʊ.dɛnt] 'student'. Notice that there are no open syllables with a

lax vowel: *Ott[ɔ], *Kaff[ɛ]. If there is a complex coda, only the first consonant contributes to a mora, and the following consonants are treated as appendical segments, as [st] in [hɛʁpst] 'autumn'. So, German also has a three-way moraic distinction but it differs from Dutch in that it lacks monomoraic syllables, and instead has trimoraic syllables.

Féry (1996) found that quantity plays a role in German stress assignment, based on a survey of the lexical database CELEX. Here I use disyllabic words for illustration. There are 3400 disyllabic words in the database. For words with initial stress, both the stressed syllable and the final unstressed one are generally bimoraic, whereas the final stressed syllable in words with final stress is trimoraic in 79 % of the words. The results are given in (23) and (24).

(23) Moraic count in disyllabic words with stress on the first syllable

2μ 2μ	2μ 3μ	3μ 2μ	3μ 3μ
472	83	17	5
82%	14%	3%	1%

(24) Moraic count in disyllabic words with stress on the second syllable

2μ 2μ	2μ 3μ	3μ 2μ	3μ 3μ
195	706	0	17
21%	77%	0%	2%

Crucially, when there is a schwa in the final syllable, stress always falls on the initial syllable; this is because schwa is non-moraic so it fails to receive stress. However, there are no disyllabic monomorphemes with initial schwa syllables (Féry 1996: 66). The opposite pattern (e.g. [Cə.CV]) is missing.

Contrary to Cohn & McCarthy (1998)'s constraint NON-FOOT(ə), Féry (1995) proposes that schwa's non-moraicity is accounted for by a constraint called NOMOSCH. It

ensures that a schwa syllable is always non-moraic and, as a consequence, always unstressed, because non-moraic syllables are too light to attract stress. As Féry (1995: 62) points out, this constraint can cancel the effect of bimoraicity, as shown in (26). For problems with the constraint NON-FOOT(ə), see discussion in chapter 3.

(25)　NOMOSCH (Féry 1995: 61): A schwa syllable is non-moraic.

(26)　Ranking for non-moraic schwa

/hubət/	NOMOSCH	BIMOR
☞　a. (húᵘᵘ).bᵊt		*
b. (húᵘᵘ).bəᵘtᵘ	*!	

Crucially, both Kager (1989, 1990) and Féry (1995) argue that moraless schwa projects a syllable, not an appendix, at the word margin. Kager & Zonneveld (1986) consider Dutch schwa to be in a word appendix optionally added at the righthand word margin. However, Kager (1990) rejects this analysis because it does not extend to schwa in nonfinal syllables, as word-internal schwa, like word-final schwa, cannot be stressed. Since nonfinal schwa displays essentially the same prosodic behavior as final schwa, the appendix analysis of schwa is not plausible. On the other hand, Féry (1995: 56) notes that syllables with non-moraic schwa are real syllables. They can have an onset, or a coda, or both, or neither. However, onsetless schwa syllables never appear word-initially. Word-internally and word-finally, they are exceptional, at least in monomorphemic words, and no words consists of a single syllable with non-moraic schwa.

In summary, both Kager (1989, 1990) and Féry (1995) argue that there are moraless schwas. The difference between them lies in *when* schwa is moraless in the derivation: i.e.

initially, but assigned a mora at a later stage, versus always non-moraic. Furthermore, both theories focus on the prosodic emptiness of schwa and provide few details on the segmental specification of schwa.

In the present theory, schwa's place and height variability are considered a side effect of its brevity – i.e. durational shortness. In fact, schwa does seem to have an articulatory target (see e.g. McDougall 2005: ch.3, Flemming & Johnson 2007), at least in some cases, when it has a longer duration.

Moraless schwas have been utilized in a number of other analyses. For example, Zuraw (2002) proposes that schwas are not moraic in Palauan, and that this accounts for how schwa behaves in reduplication. Féry (2017: 41) suggests that at least some English dialects have non-moraic schwas, suggesting that *atom* – in present terms – is [æɾᵊm]. Kinkade (1993, 1998) has proposed that all schwas in Salishan languages are non-moraic (also see Parker 2011).

Bensoukas (forthcoming) provides phonological arguments that schwa is non-moraic in Amazigh. He points out that stress falls on the rightmost closed syllable (e.g. [ák.bu] 'hole', [u.ʃúf] 'swimming', [ti.maz.da.rín] 'low (fem.pl.)'. However, closed syllables with schwa do not attract stress: e.g. [ád.fəl] 'snow'. This pattern can be explained if 'snow' is actually [(áᵘdᵘ)fᵊlᵘ], where [fᵊl] is monomoraic and therefore cannot form a foot on its own. A variety of other phonological and morphological evidence is provided for schwa's moraless status.

• *Minor syllables*

Non-moraic schwas can be seen in the context of 'minor' or 'degenerate' syllables.

Lin (1998) provides a detailed overview of the phonological and phonetic properties of minor syllables (also see Matteson 1965, Lin 1993, 1997, 1998, Shaw 1994, and Gafos 1998). A defective syllable is one that either lacks certain crucial structural elements of a regular syllable (e.g. the nucleus, the mora, the syllable node, or vocalic features of the nucleus) or does not function like a regular syllable with respect to distribution or prosody-sensitive processes. Minor syllables often appear at word edges, and tend to be insensitive to stress assignment or syllable-sensitive processes. A minor syllable is usually transcribed as containing a syllabic consonant or a consonant followed by a neutral vowel or a superscript.

Lin (1998) discusses Mon-Khmer languages such as Semai, Temiar, and Kammu. In these languages, minor syllables, which consist of one or two consonants, do not occur in isolation and occupy only unstressed positions (Shaw 1994, Gafos 1998). In Piro, a minor syllable consists of either a syllabic consonant or a consonant followed by a transitional vowel and is insensitive to stress assignment (Matteson 1965, Lin 1993, 1997). In short, minor syllables cannot occur in isolation or bear primary stress. Minor syllables may or may not be phonologically active but they all occupy less prominent prosodic positions and have restrictive distribution.

In terms of phonetic realization, minor syllables can be defined as those sub-foot defective prosodic units that contain a phonetic sonority peak which is weaker than that of a regular syllable. Moreover, the head of a minor syllable is not as sonorous as a regular syllable headed by a full vowel, and often exhibits low level phonetic variation.

In terms of representation and function, minor syllables can be broadly defined as defective prosodic units below the foot level. Lin (1998: 166) summarizes the proposed

formal representations for syllabic consonants and syllables with reduced or transitional vowels. However, the specific representation might depend on demands imposed on different languages. Lin (1998) observes the ambiguous nature of minor syllables: they are like syllables in that they contain some degree of sonority peak and may have certain properties of a syllable, and yet they are not like ordinary syllables because of the weakness of the peak, their restricted distribution and insensitivity to many prosodic processes. Ideally, the proposed representation would properly reflect the minor syllable's phonological and phonetic behavior.

Here, minor syllables are argued to be nonmoraic. Constraints that require minimum numbers of moras in feet are responsible for minor syllables' avoidance of stress. I will write nonmoraic vowels as superscripts: e.g. [pᵊ].

In summary, non-moraic syllables, particularly those with schwas, have been proposed by many previous researchers. While they do not accord with a strict interpretation of Headedness in the Prosodic Hierarchy, the following chapters will argue that they are crucial to explaining the results of acoustic experiments in Piuma Paiwan and Gujarati, and more generally in accounting for the variety of sonority-driven stress systems reported.

2.6 Residual issues

Here I lay out four residual issues that arise from my proposal. Section 2.6.1 is on the relation between non-moraic non-schwas and stress. Section 2.6.2 disucsess the (non-)existence of non-moraic mid and low vowels. Section 2.6.3 focuses on vowel

reudction. Section 2.6.4 discusses the symmetric effect in Optimality Theory. Section 2.6.5

centers on the phonotactic restrictions on schwa

2.6.1 Non-moraic non-schwas and stress

I have proposed above that schwas can be non-moraic. This section addresses the issue of

whether other vowels can have non-moraic counterparts, and how this might affect the

analysis and typology of sonority-driven stress.

It is well established that high vowels /i/ and /u/ have non-moraic counterparts: i.e.

[j] and [w]. Is it possible to capitalize on this fact and produce a sonority-driven stress

system that avoids both schwa and high vowels? Suppose that in such a system the foot

head was usually initial: e.g. [páka]. However, stress falls on the second syllable when the

first contains a high vowel and the seconds contains a non-high peripheral vowel: e.g.

[piká]. In present terms, such stress movement would have to be explained by saying that

the initial syllable's [i] is non-moraic, and it forms a minor syllable: i.e. [pj.ká].

In the present theory, the problem with such a claim is that syllables must contain

either a moraic or a [+vocalic] segment. [j] is a glide, and is [−vocalic] and [+vocoid], so

it cannot appear as a moraless nucleus.

Are there non-moraic (glide) counterparts of other vowels (e.g. /e o a/)? It is

possible that there are, but such a question is beyond the scope of this dissertation.

2.6.2 Non-moraic mid and low vowels

It is well-known that non-moraic high vowels /i/ and /u/ surface as glides [j] and [u],

respectively (e.g. Hayes 1989). In this dissertation, I propose an enriched representation of

schwa, and argue that non-moraic, monomoraic, and bimoraic schwas can co-exist in the same phonological system. The remaining question is: what about non-moraic mid and low vowels?

Hayes (1989: 256) briefly discusses the representation of glides and short vowels in moraic theory. If we assume that syllabicity is not represented on the segmental tier, we must face the fact that there are languages in which glides and short vowels contrast (Guerssel (1986) for Berber, Harris (1989) for Spanish, and Hayes & Abad (1989) for Ilokano). The contrast can be represented if no mora is assigned to an underlying glide. Hayes & Abad (1989) report that when a stem ending in /i, e, o/ is suffixed with *-an* or *-en*, the resulting hiatus is resolved by converting the stem-final vowel to a glide: /i/ and /e/ become [j], and /o/ becomes [w]. For /e/ and /o/, however, an additional process is needed to make the glide phonetically high.

So, it is hard to find reports on non-moraic mid and low vowels (e.g. the glide version of [a]). Moreover, drawing from Crosswhite's research (see section 2.6.3), the output for prominence-reducing reduction only includes [i, u, ə]. These facts suggest that there is a cut-off point between mid vowels and high vowels. As a consequence, GEN might prohibit the existence of non-moraic mid and low vowels. Of course, it is possible that there are non-moraic mid and low vowels, but a fine-detailed phonetic study is required to show compelling evidence for their existence. I leave this issue for future research.

2.6.3 Vowel reduction

The third issue is that vowel reduction can be viewed as loss of moras, at least for the prominence-reducing vowel reduction in Crosswhite (1999, 2000a, b, 2001, 2004)'s

studies.

Crosswhite distinguishes two types of vowel reduction: contrast-enhancing (moderate) vowel reduction and prominence-reducing (extreme) vowel reduction. She argues that the dichotomy is necessary in order to account for the reduction paradoxes. For example, consider the reduction patterns of Bulgarian (/i, e, ə, a, o, u/ reduces to [i, u, ə]) and Belarusian (/i, e, a, o, u/ reduces to [i, u, a]). If these two reduction patterns are superficially compared, we might arrive at the anomalous conclusion that the vowel quality of [a] is both highly marked (it undergoes reduction in Bulgarian) and highly unmarked (it serves as a reduction vowel in Belarusian). Therefore, she proposes that vowel reduction in Bulgarian belongs to the prominence-reducing type, whereas vowel reduction in Belarusian belongs to the contrast-enhancing type. In other words, languages with reduced vowels [i, u, a] are argued to maximize the perceptual distinctions for the vowel space. As mid vowels are perceptually challenging, they are neutralized in the output. Crosswhite proposes licensing constraints to restrict the appearance of mid vowels in unstressed syllables.

On the other hand, languages with reduced vowels [i, u, ə] are argued to show a prominence-reducing type of reduction. The idea is that high sonority vowels like [a, e, o] are dispreferred in unstressed syllables, so they are neutralized to low sonority vowels [i, u, ə]. Crucially, Crosswhite argues that the prominence-reducing type reduction occurs in durationally impoverished *non-moraic* syllables. For example, in Crosswhite (2000a)'s analysis of Russian, she shows that all unstressed syllables are extra short except for the

immediately pretonic one.[2] The spectrogram for the word [pə(xa.xá)ti.vəʲ] 'to chuckle from time to time' is provided in Figure 2.1.
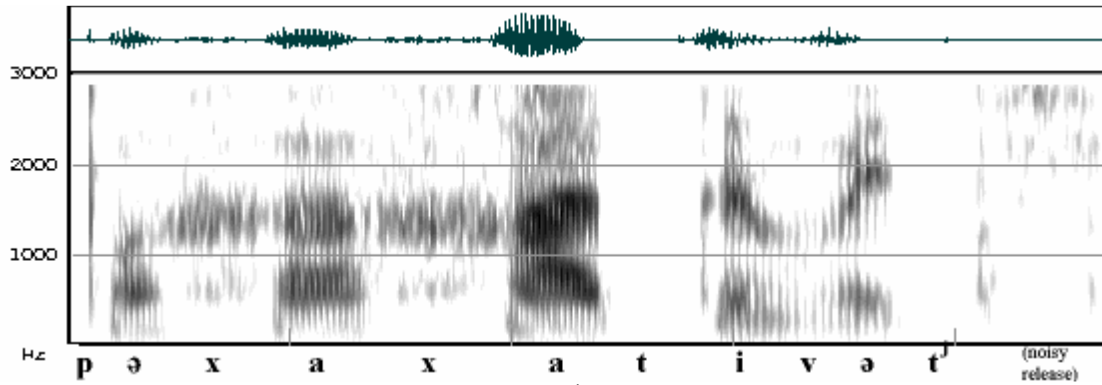
Figure 2.1: Spectrogram of [pə(xa.xá)ti.vəʲ] 'to chuckle from time to time' (from Crosswhite 2000a).

The stressed vowel and the immediately pretonic vowel are about 90 and 81 milliseconds, respectively. The remaining three vowels are very short – all around 50 milliseconds (1st vowel [pə]: 44ms, 4th vowel [ti]: 48ms, 5th vowel [vət]: 48ms). So, she argues that unfooted syllables in Russian are non-moraic. Given the moraic distribution, the constraint that motivates extreme vowel reduction is given in (27). The *NONMORAIC/−HIGH constraint assigns one violation mark to any surface non-moraic vowel that is not [i], [u], or [ə].

(27)   *NONMORAIC/−HIGH: Nonmoraic vowels may not have a sonority greater than that of [i, u].

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[2] In fact, Russian shows two types of reduction: the first pretonic syllable shows the moderate type, whereas the second pretonic and post-tonic syllable shows the extreme type. The moderate type is not the focus of the discussion here.

Apart from Russian, Crosswhite (2000b) also suggests that the same formal device can be used to account for extreme vowel reduction in Catalan and Brazilian Portuguese. However, due to the lack of instrumental evidence for Catalan, it is not clear whether we can explain the pattern by using the constraint *NONMORAIC/−HIGH to replace *UNSTRESSED/−HIGH. Further investigation is needed. It should also be noted that some recent studies have argued that the extreme reduction to schwa in Russian is gradient, with vowel height being strongly dependent on vowel duration (Barnes 2006, 2007, also see Iosad 2012). Under this view, extreme reduction stems in phonetics, not phonology.

In short, following Crosswhite's work, the prominence-reducing type of reduction can be viewed as loss of moras. If this is on the right track, then there is no need to refer to the sonority of the non-head position of the foot or the unfooted syllables. It can therefore be reduced to the constraints on moraicity.

2.6.4 Symmetric effect

As discussed in section 2.2.2, one of the empirical consequences of the theory proposed here is that sonority-driven stress does not exist. Suppose that this is true for all languages reported to have sonority-driven stress; it presents interesting challenges in analytical frameworks such as Optimality Theory, because of the property of 'symmetric effect'.

As de Lacy (2007: 301) notes, no constraint is phenomenon-specific in Optimality Theory. Constraints with the form *π/*p* (π is a prosodic category, *p* is a property like sonority or tone) have many possible resolutions. In general, there are two repair strategies to satisfy *π/*p*. One is to change the prosodic structure but keep sonority constant. The other is to change the sonority but keep the prosodic structure constant. The constraints

used to account for sonority-driven stress have the similar form in Kenstowicz (1997)'s and de Lacy (2002, 2004, 2006)'s theories.

For example, de Lacy (2002, 2004, 2006) proposes that there is a unifying theoretical mechanism that accounts for sonority-driven stress and this same mechanism accounts for interactions at all prosodic levels. Following his work, the sonority hierarchy can be expressed through the form of constraints in Optimality Theory. The symmetric constraint forms and definitions are given schematically in (28). The category foot head (HD) refers to the stressed syllable of a foot while the category foot non-head (NON-HD) refers to the unstressed syllable of a foot.

(28)   Sonority constraints *(NON-)HD$_\alpha$/β

    a. *HD$_\alpha\leq\beta$

       Assign a violation for every segment in Hd$_\alpha$ that is lower than or equal to β on scale F.

    b. *NON-HD$_\alpha\geq\beta$

       Assign a violation for every segment in non-Hd$_\alpha$ that is greater than or equal to β on scale F.

In general, *HD$_\alpha\leq\beta$ and *NON-HD$_\alpha\geq\beta$ have the ability to restrict certain vowels of different sonority in head and non-head positions. The constraint *HD$_\alpha\leq\beta$ plays an essential role in sonority-driven systems since it can ban vowels with low sonority in head position. An example of such a constraint is *HDFt$\leq$\{e,o\}, penalizing vowels in the head position of a foot that have the sonority of a mid peripheral vowel or smaller (e.g. [e o i u]). Similarly,

*NON-HDFt≥{a} is violated when a very high sonority vowel appears in the non-head syllable of a foot. The action of such constraints is illustrated in the tableaux below.

(29) Constraint on head sonority

	/paki/	*HDFt≤{e,o}	ALIGN-HD-R
☞	a. (páki)		*
	b. (pakí)	*!	

(30) Constraint on non-head sonority

	/paki/	*NON-HDFt≥{a}	ALIGN-HD-R
☞	a. (páki)		*
	b. (pakí)	*!	

In (29), the constraint penalizes a lower sonority vowel in head position, so candidate (29b) is ruled out. In (30), the constraint penalizes a higher sonority vowel in non-head position, so candidate (30b) is eliminated. However, my theory predicts that such constraints cannot exist.

Moreover, *(NON-)HD$_\alpha$/β is necessary to account for stress-driven neutralization, deletion, metathesis, and coalescence (de Lacy 2007: 301-305). In a sense, such restrictions are 'stress-driven sonority/tone': they are cases where prosodic structure is kept constant and sonority/tone changes.

If sonority-driven stress does not exist, the existence of *HD$_\alpha$≤β and *NON-HD$_\alpha$≥β is problematic. The repair strategies for the constraint *(NON-)HD$_\alpha$/β could be either to fix the prosody or change the vowel sonority. As a consequence, we lose the ability to account for stress-driven phenomena other than sonority-driven stress, such as neutralization, deletion, metathesis, and coalescence.

The fundamental problem is one of 'too many solutions' (e.g. Blumenfeld 2006).

While the *(NON-)HD$_\alpha$/β constraints can motivate vowel reduction and deletion, they should not be permitted to motivate relocation of metrical heads. It is not the goal of this dissertation to propose a solution to the 'too many solutions' problem. I leave it for future research.

2.6.5 Phonotactic restrictions on schwa

Schwa is often restricted in terms of where it can appear. For example, cross-linguistically, it is common that schwa is banned in the final position of a word, as observed in Yupik (Reed et al. 1977), Chukchi (Kenstowicz 1994), Moroccan Arabic (Dell & Elmedlaoui 2002) and Javanese (Horne 1974).

   Similarly, Gordon & Applebaum (2010) argue that Kabardian bans phrase-final schwa. To explain the restriction, Gordon & Applebaum (2010: 63) formulate the constraint below.

(31)   *FINAL-ə: /ə/ does not occur at the right edge of a prosodic phrase.

   However, I will argue that the ban of absolute word-final schwa in Piuma Paiwan is due to schwa's moraicity and the requirement of foot form constraints. I argue that the input /CVCVCə/ surfaces as [CVCVC], not *[CVCVCə] and *[CVCVCᵊ]. Crucially, the output [CVCVCə] is penalized by a moraicity constraint which forbids schwa to bear a mora. The output [CVCVCᵊ] is penalized by foot form constraints such as FTBINµ. See section 3.5.7 in chapter 3 for more details.

The deeper issue is whether the proposal for Piuma Paiwan will generalize to all cases where final schwa is banned, and so subsume *FINAL-ə. At this point, it is far from clear whether that will be the case. However, I believe that examining bans on final schwas through the lense of non-moraic schwa could provide an explanation, as in Piuma Paiwan.

Schwa is also often banned in other structures. Oostendorp (1995) identifies a number of restrictions, including requirements that (a) schwa cannot appear absolute word-initially, (b) schwa can only appear in open syllables, (c) schwa must occur in closed syllables. Oostendorp (1995: 16) points out that schwa can have phonotactic subtleties in the same language: e.g. epenthetic schwa can appear inside closed syllables, while underlying schwas cannot.

It is beyond the scope of this dissertation to examine all phonotactic restrictions on schwa and how they might be explained with the approach advocated here: i.e. that schwa can be non-moraic in particularly environments, and there are conditions on non-moraic segments. However, the way forward is clear: hopefully, all cases of phonotactic restrictions on schwa can be reduced to where non-moraic schwa and degenerate syllables can and cannot appear.

2.7 Summary

To summarize, the present theory encapsulates the following major ideas:

(32)   Main proposals

    a. Non-moraic schwa is possible.

b. Moraless syllables are possible (if they contain a schwa).

c. Non-moraic schwa and moraic schwa can coexist in the same grammar.

d. There are pressures for schwa to be non-moraic (*μ/ə).

e. There are pressues for schwa to be moraic, both direct (HD-σ) and indirect (e.g. FTBINμ).

f. Prosody is myopic: No markedness constraint can contain structures that include prosodic nodes more than 2 levels apart.

In Optimality Theory terms, the following representations of syllables with schwa are possible:

(33) Syllables with schwa
      a. Minor/defective syllable   b. Monomoraic schwa   c. Bimoraic schwa
      with nonmoraic schwa

                [Cᵒ]   [Cə]   [Cə:]
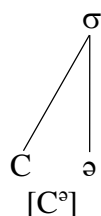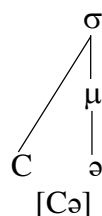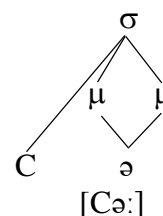
The following constraints will prove significant in producing the typology of stress systems that are sensitive to schwa:

(34) Useful constraints on (non-)moraic schwas

      a. *μ/ə "Incur a violation for each schwa that is not dominated by a μ."

b. HEADEDNESS-σ (HD-σ) "Incur a violation for each σ that does not dominate a μ node."

c. FTBINμ "Incur a violation for every Ft node that does not dominate two and only two moras."

Chapters 3 and 4 will illustrate the theory with analyses of Piuma Paiwan and Gujarati. Chapter 5 will discuss the typology of metrical systems with respect to non-moraic schwa.

CHAPTER 3

MORALESS SCHWA IN PIUMA PAIWAN

3.1 Introduction

The goal of this chapter is to show that moraic and non-moraic schwa can co-exist in the same phonological system. I will show that schwa is usually non-moraic in Piuma Paiwan (hereafter 'P'). However, under certain foot-related conditions, schwa is required to bear mora. Strikingly, schwa is required to be monomoraic when in the non-head position of a foot, and bimoraic when in the head syllable of a foot. The result is that P has *three* types of schwa: bimoraic [əː], monomoraic [ə], and non-moraic [ᵊ]. The different kinds of schwa have significantly distinct acoustic effects. Moraic quantity determines duration (e.g. Hubbard 1995, Broselow *et al*. 1997), so bimoraic schwa is longer than monomoraic schwa, which is longer than non-moraic schwa. There are also other consequences of being mora-less: non-moraic vowels are shown to have greater variation in quality (F1 and F2) than moraic vowels.

All descriptions of P agree that the default position for stress is the penult. They also agree that stress avoids the lowest sonority vowel – schwa – when there is a more sonorous one in the final syllable (Chen 2009a, b, Yeh 2011). However, surprisingly, stress movement off of a penultimate schwa to a *final schwa* is also reported. Examples are given in (1).

(1)   Piuma Paiwan's sonority-driven stress according to Chen (2009a, b) and Yeh (2011: 116-117)

a. Default stress on penult

[káka]   'sibling'   [gádu]   'mountain'

[vúvu]   'grandparents'   [tsáviʎ]   'year'

[lígim]   'needle'   [tútaŋ]   'aluminium'

[tsaʎíŋa]   'ear'   [píku]   'elbow'

[vitsúka]   'stomach'   [ʎavátsaq]   'horsefly'

[rágəd]   'pebble'   [tídəq]   'interval'

[maqípər]   'unlucky'

b. Stress falls on the final syllable if the penult contains a schwa and the final is not schwa

[kərí]   'small'   [qurəpús]   'cloud'

[cəvús]   'sugarcane'   [qapədú]   'gall'

[kəmán]   'to eat'   [kəməláŋ]   'to know'

c. Stress falls on the final syllable if both penult and final syllables contain schwa

[ləʎə́t]   'lip'   [ʎisəqə́s]   'nit'

[tsəmə́ɭ]   'grass'   [masəŋsə́ŋ]   'to make something'

In (1a), stress falls on the penultimate syllable – the default position – when neither vowel is schwa. Notice that closed syllables are not heavy – e.g. [tútaŋ], *[tutáŋ].

However, stress is repelled to the final syllable when the penult contains a schwa and the final syllable contains another vowel – all of which are more sonorous than schwa,

as in (1b). In other words, since schwa is less sonorous than other vowels, it repels stress away from the default position, so it is a case of 'sonority-driven stress'.

Interestingly, if both the penult and ultima contain schwas, stress falls on the final syllable, as in (1c). This situation is somewhat surprising because both vowels in (1c) have the same sonority, so one might expect stress to fall on the default penultimate position.

This chapter argues that previous descriptions are accurate about the distribution of stress, but are inaccurate in certain other crucial respects. Specifically, the prosodic structure of P words is given in (2). Moraic content is specified here for clarity.

(2)   The new hypothesis: Piuma Paiwan's prosodic structure

    a.   [(CV́$^\mu$.CV$^\mu$)]

    b.   [(CV́$^\mu$.CV$^\mu$C)]

    c.   [C$^\circ$(CV́:$^{\mu\mu}$)]   i.e. [kᵊríː], [qapᵊdúː]

    d.   [C$^\circ$(CV́:$^{\mu\mu}$C)]   i.e. [cᵊvúːs], [qurᵊpúːs]

    e.   [(CV́$^\mu$.Cə$^\mu$C)]

    f.   [C$^\circ$(Có̵:$^{\mu\mu}$C)]   i.e. [lᵊʎə́ːt], [ʎisᵊqə́ːs]

A crucial difference between the present findings and previous descriptions is that in words with final stress, the final vowel is long. Also, in words with penultimate schwa, the schwa is very short – much shorter than when schwa is final.

This chapter will use the results from my fieldwork and experiments to argue that every word in P ends in a right-aligned bimoraic trochaic foot, as in [CV(CV́.CV)]. The problem for feet is that schwas prefer to be non-moraic. The consequence for words with

a /CəCV/ shape is that the final vowel must become bimoraic – i.e. lengthen – so as to create a bimoraic foot: i.e. [Cᵊ(CV́ːᵘᵘ)], not the monomoraic *[(Cᵊ.CV́ᵘ)] or *[Cᵊ(CV́ːᵘ)]. However, for /CVCəC/ words there is a problem: the form *[(CV́ᵘ.CᵊC)] has an illicit monomoraic foot. To resolve this problem, schwa in non-head position within a foot is forced to have a mora: i.e. [(CV́ᵘ.CəᵘC)]. Finally, when there are *only* schwas in the last two syllables of a word, the final schwa is stressed and becomes bimoraic: [Cᵊ(Cə́ᵘᵘC)].

This chapter will present evidence that are three schwas in P: bimoraic in [Cᵊ(Cə́ᵘᵘC)] words, monomoraic in [(CV́ᵘ.CəᵘC)] words, and non-moraic elsewhere.

Importantly, this chapter argues that P's stress system is *not* directly sensitive to sonority: there is no constraint that bans stressed schwas (cf. Kenstowicz 1997, de Lacy 2002, 2004). Instead, schwa typically lacks a mora due to the restrictions on vowel moraicity introduced in chapter 2. Constraints on the moraic content of feet are then responsible for the footing of schwa.

The acoustic effects of the three schwa types are easy to detect. Moras are realized as an increase in duration, so bimoraic schwas have the greatest duration of the three types, then monomoraic schwas, then non-moraic schwas. Vowel quality variation is also shown to distinguish non-moraic from moraic schwas. Stress, on the other hand, is shown to be detectable through F0 and intensity.

The importance of P is that it shows that moraic and non-moraic schwas can co-exist in the same phonological system, and that their distribution is predictable. Furthermore, Piuma illustrates well how the difference between moraic and non-moraic schwa can be detected through acoustic analysis.

The observations made here about P are based on two experiments conducted by

the author during a field trip in southern Taiwan. The details of these experiments are provided in section 3.3. One experiment was on native words while the other involved wug words. Acoustic correlates of stressed/unstressed vowels were measured, including intensity, duration, F0, F1 and F2.

Section 3.4 discusses the acoustic analysis. It supports previous claims that stress avoids penultimate syllables when they contain schwa. Of the five types of phonetic evidence examined, F0 provides particularly clear evidence for stress avoiding schwa: stressed vowels always have a higher F0 than unstressed vowels. Intensity is also shown to be higher for stressed vowels. A duration model is presented and shown to support the hypothesis presented above, i.e. that there are three types of schwa, each of which differ in duration.

A phonological analysis of the Piuma Paiwan system is provided in section 3.5, and alternative theories are discussed. The broader theoretical implications of Piuma Paiwan's system are discussed in section 3.6. Section 3.7 presents interim conclusions.

3.2 Theory

The key to understanding the behavior of schwa, and of sonority-driven stress, is in understanding the nature of syllables. Crucially, some syllables can lack moras. Such 'minor syllables' are widely attested (Matteson 1965, Shaw 1994, Gafos 1998, Lin 1993, 1997, 1998). They have a variety of detectable behaviors, including the repulsion of metrical structure. I argue, agreeing with much other research (e.g. Kager 1989, van Oostendorp 2000), that schwa is particularly susceptible to avoiding a mora. Its susceptibility is due to its low sonority – a point predicted by Zec (2007)'s theory of mora-

sonority relations.

3.2.1 Minor Syllables

Lin (1998) provides a detailed overview of the phonological and phonetic properties of minor syllables. A defective syllable is one that either lacks certain crucial structural elements of a regular syllable (e.g. the nucleus, the mora, the syllable node, or vocalic features of the nucleus) or does not function like a regular syllable with respect to distribution or prosody-sensitive processes. Minor syllables often appear at word edges, and tend to be insensitive to stress assignment or syllable-sensitive processes. A minor syllable is usually transcribed as containing a syllabic consonant or a consonant followed by a neutral vowel or a superscript.

Lin (1998) discusses Mon-Khmer languages such as Semai, Temiar, and Kammu. In these languages, minor syllables, which consist of one or two consonants, do not occur in isolation and occupy only unstressed positions (Shaw 1994, Gafos 1998). In Piro, a minor syllable consists of either a syllabic consonant or a consonant followed by a transitional vowel and is insensitive to stress assignment (Matteson 1965, Lin 1993, 1997). In short, minor syllables cannot occur in isolation or bear primary stress. Minor syllables may or may not be phonologically active but they all occupy less prominent prosodic positions and are restricted in their distribution.

In terms of phonetic realization, minor syllables can be defined as those sub-foot defective prosodic units that contain a phonetic sonority peak which is weaker than that of a regular syllable. Moreover, the head of a minor syllable is not as sonorous as a regular syllable headed by a full vowel, and often exhibits low level phonetic variation.

In terms of representation and function, minor syllables can be broadly defined as defective prosodic units below the foot level. Lin (1998: 166) summarizes the proposed formal representations for syllabic consonants and syllables with reduced or transitional vowels. However, the specific representation might depend on language-specific demands. Lin (1998) observes the ambiguous nature of minor syllables: they are like syllables in that they contain some degree of sonority peak and may have certain properties of a syllable, and yet they are not like ordinary syllables because of the weakness of the peak, their restricted distribution and insensitivity to many prosodic processes. Ideally, the proposed representation would properly reflect the minor syllable's phonological and phonetic behavior.

Here, minor syllables are argued to be non-moraic. Constraints that require minimum numbers of moras in feet are responsible for minor syllables' avoidance of stress. I will write non-moraic vowels as superscripts: e.g. [pᵊ].

3.2.2 Minor Syllables in Piuma Paiwan

In this chapter, I will show that minor syllables play a crucial role in Piuma Paiwan stress assignment. That is, a syllable that contains a schwa is typically moraless. Consequently, it cannot be the head mora of a foot, and so cannot bear stress. Such non-moraic schwas share certain acoustic properties: they have very short duration (perhaps the minimum necessary duration for a vowel), and they are heavily influenced by their surrounding environment.

However, foot constraints can force schwas to be moraic. In /CuCəC/ words, feet must have two moras, so /ə/ has a mora on the surface: [(CúCəC)]. In the situation where

a word contains only schwas (i.e. /CəCəC/), the foot binarity requirement means that the rightmost schwa ends up with two moras: [Cᵊ(Cə$^{\mu\mu}$C)]. As a consequence, three types of schwa – moraic, monomoraic, and bimoraic – exist in Piuma Paiwan. The representation for all types is shown in (3).

(3)　　Representation
　　　　a. Minor/defective syllable　　b. Monomoraic schwa　　c. Bimoraic schwa
　　　　with non-moraic schwa

In (3b) and (3c), schwa is directly dominated by a mora and two moras, respectively. By contrast, in (3a) the schwa is defective, so it does not bear a mora, instead being immediately dominated by a syllable node.

　　　　A formal account of stress assignment in P using Optimality Theory will be presented in section 3.5 (Prince & Smolensky 2004). Here I lay out the constraints that are fundamental in dealing with schwa and its moraic content and sketch the crucial rankings.

(4)　　Constraints for stress assignment in Piuma Paiwan

　　　　a. Constraints on moraicity (after Zec 2007, also see Prince & Smolensky 2004)

　　　　*μ/ə

　　　　"Incur a violation for every schwa that bears a mora."

　　　　(From the family of constraints *μ/ə, *μ/{i,u}, *μ/{e,o}, *μ/a)

b. Constraints on headedness (Selkirk 1981, 1984, 1995, Nespor & Vogel 1986).

HEADEDNESS schema:

"Incur a violation for any node *n* s.t. *n* does not dominate some node *m* where *n* is on layer *i* and *m* is on layer *i-1*."

HEADEDNESSFT "Incur a violation for any Ft that does not dominate a σ."

HEADEDNESSσ "Incur a violation for any σ that does not dominate a μ."

c. Constraints on foot content

FTBIN "Feet either branch at the Ft level or syllable level, but not both."

(Adapted from Prince & Smolensky 1993/2004, McCarthy & Prince 1993/2001)

FTBINμ "Feet contain two moras." (after Élias-Ulloa 2006)

For the constraints on moraicity, there is a ready-made motivation for moraless schwa: the *NUC/x constraints of Prince & Smolensky (2004), with moraic versions from Zec (2007: 180). The sonority hierarchy of syllable peaks is incorporated into the grammar as a set of markedness constraints with a stringent form. Here I only focus on vowels.

The set of constraints in (4a), while banning all vowels from the nuclear position, places the strongest ban on the least sonorous vowel schwa and the weakest on low vowels. In other words, schwa is the least desirable mora-bearing segment. In P, *μ/ə plays a crucial role because it forbids schwas to be moraic.

In conflict with *μ/ə are the HEADEDNESS constraints (Selkirk 1995). Every foot node should dominate a syllable node and syllable nodes must dominate moras. Consequently, non-moraic schwas violate HEADEDNESSσ.

The basic 'moraless schwa' ranking is given in (5). Crucially, moraic schwa is

prohibited because the constraint *μ/ə dominates HEADEDNESSσ. Candidate (5b) fatally

violates *μ/ə. In the case where both vowels are moraless, as shown in candidate (5c), both

syllables violate the constraint HEADEDNESSσ. As a result, candidate (5a) is the optimal

output under the constraint ranking (assuming that HEADEDNESSσ outranks all other *μ/x

constraints).

(5) Basic moraless schwa ranking

/tətu/	*μ/ə	HEADEDNESSσ	*μ/{ə,i/u}
☞ a. tᵊ.tuᵘ		*	*
b. təᵘ.tuᵘ	*!		* *
c. tᵊ.tʷ		**!	

What makes the moraless schwa ranking interesting is that it can be blocked in

specific contexts. For example, FTBINμ requires feet to have two moras, so if FTBINμ

outranks *μ/ə, then /ə/ can be forced to be bimoraic for the good of the foot. For example,

as shown in the tableau below, the final /ə/ is forced to be moraic to make the foot minimally

bimoraic. However, the first schwa is not forced to have a mora because it is not in the

foot, and so it can be non-moraic.

(6) Blocking moraless schwa

/tətutə/	FTBINμ	*μ/ə	HEADEDNESSσ
☞ a. tᵊ(túᵘtəᵘ)		*	*
b. tᵊ(túᵘ)tᵊ	*!		* *
c. təᵘ(túᵘ.təᵘ)		* *!	

So, while schwas can be forced to be non-moraic, there are ways to require their

moraicity in particular environments in the same phonological system. Piuma Paiwan

provides a particularly striking example of just this situation, with foot restrictions

requiring schwa to be monomoraic in some environments, and even bimoraic in others, while *μ/ə forces them to be non-moraic elsewhere. The goal of this chapter is to illustrate the basic predictions of the moraic and non-moraic representation of schwa and its associated constraints, i.e. that moraic and non-moraic schwa can co-exist in the same phonological system. Later chapters will address the further predictions of the theory, including predictions regarding metrical structure and other minor syllables, including those not involving schwa.

3.3 Methodology

3.3.1 Background

Paiwan is an Austronesian language spoken in the south and southeast of Taiwan. The number of speakers is estimated to be close to 100,000, according to the 2017 survey of the Council of Indigenous Peoples in Taiwan. However, the total number of native Paiwan speakers is far less than the population. Paiwan, like other Austronesian languages spoken in Taiwan, lacks its own writing system. This study focuses on Piuma Paiwan, a Paiwan dialect mainly spoken in Pinghe Village, Pingtung County.

Some background on Piuma Paiwan segments, syllable, and word structure is necessary to understand stress assignment. Piuma Paiwan has four surface vowels. All the vowels are contrastive (Chen 2009a). The only restriction on vowel distribution relates to schwa: my subjects reported that schwa never occurs in the absolute final position of a word. For example, [və.və] 'sprouts' in other Paiwan dialects is [və.vu] in Piuma Paiwan.

(7)   Piuma Paiwan's vowel inventory

Front	Central	Back
i		u
	ə	
	a	

(8)   Piuma Paiwan's consonant inventory (adopted from Yeh 2011)

	Labial	Alveolar	Retroflex	Palatal	Velar	Uvular	Glottal
Stop	p b	t d	ɖ	c ɟ	k g	q	ʔ
Fricative	v	s z				ʁ	
Affricate		ts					
Nasal	m	n			ŋ		
Trill		r					
Liquid			ɭ	ʎ			
Glide	w			j			

The Piuma Paiwan consonant inventory is given in (8). The syllable structure of the language is (C)(V)V(C) (Yeh 2011: 10). Onsets and codas are optional, as shown by [u.ta] 'also'. Adjacent vowels are tautosyllabic diphthongs (Yeh 2011).

Morphologically, Piuma Paiwan is an agglutinative language; grammatical information is encoded by way of affixation. Prefixes do not affect stress assignment: e.g. [vása] 'taro' → [ki-vása] 'go get taro'. However, suffixes may attract stress from the default position due to vowel coalescence or glide formation (Yeh 2011: 113). For example, the imperative suffix -*i* becomes a glide when the preceding verb stem ends with a vowel, resulting in a closed syllable: e.g. /kəvava-i/ → [kəvaváj] 'drink wine'. Morpheme boundaries will be marked where relevant in this study. Syntactic classes do not affect the assignment of stress in Piuma Paiwan (Chen 2004: 36).

● *Previous stress descriptions*

Previous descriptions of stress in Piuma Paiwan report that it is sonority-driven (Chen

2009a, b, Yeh 2011). That is, stress is sensitive to vowel sonority. While there is disagreement on whether stress in Piuma Paiwan is quantity-sensitive, two themes emerge from the descriptions: (a) the default position for stress is the penult, and (b) stress avoids [ə].

(9)   Piuma Paiwan's sonority-driven stress according to Chen (2009a, b) and Yeh (2011: 116-117)

a. Default stress on penult

[káka]	'sibling'	[gádu]	'mountain'
[vúvu]	'grandparents'	[tsáviʎ]	'year'
[lígim]	'needle'	[tútaŋ]	'aluminium'
[tsaʎíŋa]	'ear'	[píku]	'elbow'
[vitsúka]	'stomach'	[ʎavátsaq]	'horsefly'
[rágəd]	'pebble'	[tídəq]	'interval'
[maqípər]	'unlucky'		

b. Stress falls on the final syllable if the penult contains a schwa and the final is not schwa

[kərí]	'small'	[qurəpús]	'cloud'
[cəvús]	'sugarcane'	[qapədú]	'gall'
[kəmán]	'to eat'	[kəməláŋ]	'to know'

c. Stress falls on the final syllable if both penult and final syllables contain schwa

[ləʎə́t]	'lip'	[ʎisəqə́s]	'nit'
[tsəmə́l]	'grass'	[masəŋsə́ŋ]	'to make something'

In (9a), stress falls on the penultimate syllable – the default position – when both vowels are the same (except for schwa). However, stress is retracted onto the final syllable when the penult contains a schwa, as in (9b). If both the penult and ultima contain a schwa, stress falls on the final position, as in (9c).

In other words, descriptively, [ə] is less sonorous than other vowels and it repels stress away from the default position, so this system is a case of 'sonority-driven stress'. Importantly, stress does not avoid high vowels for low vowels, in spite of the fact that high vowels are less sonorous than [a]: e.g. [tútaŋ] 'aluminum', and [qíʎas] 'moon' (Chen 2009b: 597-599). So, the sonority hierarchy distinctions for stress in Piuma Paiwan can be summarized as follows:

(10)   Sonority hierarchy for stress assignment in Piuma Paiwan

peripheral vowels > mid central

   'a, i, u'   **'ə'**

Finally, descriptions disagree as to whether syllable weight plays a role in stress assignment. Chen (2009b) claims that Piuma Paiwan has a quantity-insensitive stress system. However, Yeh (2011) reports that CVV and VV are heavy, so stress is attracted to heavy syllables. As it is not the purpose of this study to determine how or whether syllable weight plays a role in stress, CVV and VV syllables were excluded from the experiments entirely.

(11)   Acoustic correlates of stress reported for Paiwan

     a. Longer duration?   Chen (2004)

     b. Higher pitch   Chen (2004, 2009b), Yeh (2011)

Previous work on Piuma Paiwan consistently reports that stressed vowels have higher pitch than unstressed vowels (Chen 2004, Chen 2009b, Yeh 2011). Moreover, Chen (2004) found that the duration of a stressed vowel is longer overall than an unstressed one – more than 1.7 times that of an unstressed vowel. It should be noted that the methodology used in Chen (2004)'s work is not fully discussed. Chen (2004: 32) only mentions that all the oral data in that study was based on natural speech, elicitation, narratives, and conversation. However, Chen (2009b) measured the duration of words with the same vowel and found that final syllables are generally longer than penultimate syllables, regardless of whether stress fell on the penult. That is, the duration of the final syllable seems mostly influenced by phrase-final lengthening. Chen (2009b: 606) also reports that vowel duration in closed syllables (e.g. [vat] and [vut]) is shorter than that in open syllables (e.g. [va] and [vu]). Consequently, Chen (2009b) concludes that vowel duration may not be a strong correlate of stress in Piuma Paiwan. Therefore, metrical heads in Piuma Paiwan are probably realized most robustly through F0 realization. Finally, Chen (2004, 2009b) reported that intensity is not an acoustic correlate of stress in Piuma Paiwan.

However, two crucial parts are missing in previous studies. First, the studies only examined the acoustic properties (duration, F0, and intensity) for the default penultimate stress position. Chen (2009b) solely focused on words with the shape [CV.CV] (where V ≠ [ə]). In other words, no words with schwa such as [Cə.CV], [Cə.CVC], [CV.CəC], or

[Cə.CəC] were examined. It is then not yet clear how stressed and unstressed schwas behave acoustically in different syllable positions. Second, vowel quality (i.e. F1 and F2) was not studied, so it is unclear whether vowel quality is conditioned by stress. The present experiment aims to fill these gaps.

Most importantly, the present experiment was designed to examine the acoustic differences – if there are any – between the schwas in various metrical positions.

Finally, Ferrell (1982) reports that stress in the Kulalao dialect involves an increase in intensity of the stressed vowel, which is always the penultimate vowel in the phrase (noun phrase, verb phrase, or adverbial phrase). Unstressed vowels are unaffected qualitatively. However, the description is impressionistic; no acoustic measurements are provided.

● *Current proposal*

In the following discussion, I will evaluate the previous descriptions of P's stress. I conclude that there is strong acoustic evidence that stress avoids [ə] in penultimate position, just as claimed in previous descriptions. Specifically, F0 peaks over the stressed vowel, so – as expected – in [CəCV] words F0 peaks over the final syllable. Also, the stressed vowel is more intense than unstressed vowels, putting aside the effect of coda consonants on intensity.

However, I will also show that previous descriptions failed to report crucial details about vowel length, duration, and vowel quality. While stressed vowels are not phonetically realized with greater duration, vowels are phonologically lengthened and shortened in several stress-related environments.

Specifically, stressed vowels are lengthened in words with the underlying form /CəCV(C)/. So, /kəri/ is realized as [kə̆ríː], /qətsap/ as [qə̆tsáːp], and /tsəkə́ʎ/ as [tsə̆kə́ːʎ].

In addition, schwas are shortened in penultimate position. So, /kəri/ is realized as [kə̆ríː], not *[kəríː]. Schwas are *not* short in final unstressed position, however: [tútət], *[tútə̆t].

In section 3.5, I will argue that vowel length can be explained by the theory of schwa moraicity proposed in this dissertation.

3.3.2 Goal of the experiments

The goal of the experiment is to provide acoustic evidence to support the proposal that stress avoidance of schwa in Piuma Paiwan is due to schwa's moraic content, rather than its low sonority. Therefore, [ə] is the focus of the experiment.

Forms such as /CuCu/, /CuCuC/, /CəCu/, /CəCuC/, /CəCəC/, and /CuCəC/ play an essential role in solving the mystery of schwa because they contain schwa in all environments that are relevant for stress assignment (see section 3.3.1). Of the three full vowels, only the high vowel [u] is examined in this study (see section 3.3.2).

The hypothesis specified above predicts that the underlying forms will have the following phonological surface forms, with the phonetic realizations as shown below:

(12)   The new hypothesis

Phonological	$\rightarrow$	Phonological	$\rightarrow$	Phonetic
Input		Output		Form
a. /Cu₁Cu₂/	$\rightarrow$	$[(Cú_1{}^{\mu}.Cu_2{}^{\mu})]$	$\rightarrow$	$[\![\,{}^{\prime}Cu_1Cu_2\,]\!]$
b. /Cu₃Cu₄C/	$\rightarrow$	$[(Cú_3{}^{\mu}.Cu_4{}^{\mu}C)]$	$\rightarrow$	$[\![\,{}^{\prime}Cu_3CuC_4\,]\!]$
c. /Cə₁Cu₅/	$\rightarrow$	$[C^{\circ 1}(Cú_5{}^{\mu\mu})]$	$\rightarrow$	$[\![C\breve{\textrm{ə}}_1{}^{\prime}Cu_{:5}]\!]$
d. /Cə₂Cu₆C/	$\rightarrow$	$[C^{\circ 2}(Cú_6{}^{\mu\mu}C)]$	$\rightarrow$	$[\![C\breve{\textrm{ə}}_2{}^{\prime}Cu_{:6}C]\!]$
e. /Cə₃Cə₄C/	$\rightarrow$	$[C^{\circ 3}(C\acute{\textrm{ə}}_4{}^{\mu\mu}C)]$	$\rightarrow$	$[\![C\breve{\textrm{ə}}_3{}^{\prime}C\textrm{ə}_{:4}C]\!]$
f. /Cu₇Cə₅C/	$\rightarrow$	$[(Cú_7{}^{\mu}.Cə_5{}^{\mu}C)]$	$\rightarrow$	$[\![\,{}^{\prime}Cu_7Cə_5C]\!]$

Note that u5, u6, and ə4 all become bimoraic in the phonological output; ə5 is monomoraic, and all other schwas are non-moraic.

For ease of exposition, all vowels are numbered. For example, u6 refers to the /u/ in /CəCuC/, the [u] in $[C^{\circ 2}(Cú_6{}^{\mu\mu}C)]$, or the ⟦u⟧ in $[\![C\breve{\textrm{ə}}_2{}^{\prime}Cu_{:6}C]\!]$, depending on which level is specified. The following experiment description and results will refer to this numbering system.

The hypothesis above predicts that ə1, ə2, and ə3 should be realized very similarly, if not identically – they are all initial, non-heads, and non-moraic. In comparison, ə5 should be significantly longer than ə1, ə2, and ə3 because it has a mora. The longest schwa should be ə4 because it is bimoraic. On the other hand, there should be some acoustic similarity between ə1, ə2, ə3, and ə5 because they are all unstressed, unlike ə4. In terms of duration,

then, the prediction is (all else being equal): $\text{ə}4 > \text{ə}5 > \text{ə}1, \text{ə}2, \text{ə}3$. For stress-relevant properties, though, $\text{ə}4$ should be different from all other schwas, and all other schwas should share acoustic properties.

The longest u's are predicted to be u6 and u5 since they are both bimoraic. All other u's should be shorter. If stress has no effect on duration, then the prediction is that u6 and u5 will be longer than all other u's (i.e. u1, u2, u3, u4, u7). However, for acoustic properties that mark stress, u2 and u4 should pattern together, while all other u's should share properties.

(13)   Predicted acoustic similarity groups for native words

Penultimate (default)	Ultimate (avoiding schwa)
$^{\mid}$Cu$_1$.Cu$_2$	Cə$_1$. $^{\mid}$Cu:$_5$
$^{\mid}$Cu$_3$.Cu$_4$C	Cə$_2$. $^{\mid}$Cu:$_6$C
$^{\mid}$Cu$_7$.Cə$_5$C	Cə$_3$. $^{\mid}$Cə:$_4$C

Wug words were employed in this study to test the productivity of the stress pattern in P (Berko 1958). Both disyllabic and trisyllabic words were used in the wug experiment. Disyllabic forms are similar to native words mentioned above: /CuCu/, /CuCuC/, /CuCəC/, /CəCu/, /CəCuC/, and /CəCəC/. The vowel [u] is the focus here (see section 3.3.2). The acoustic pattern for [u]s and schwas are consistent with the summary for native words.

(14) Predicted stress patterns for nonce words

Penultimate (default)	Ultimate (avoiding schwa)
⟦ˈCu.Cu⟧	⟦Cə̆.ˈCuː⟧
⟦ˈCu.CuC⟧	⟦Cə̆.ˈCuːC⟧
⟦ˈCu.CəC⟧	⟦Cə̆.ˈCəːC⟧
⟦Cu.ˈCu.Cu⟧	⟦Cu.Cə̆.ˈCuː⟧
⟦Cu.ˈCu.CuC⟧	⟦Cu.Cə̆.ˈCuːC⟧
	⟦Cu.Cə̆.ˈCəːC⟧

Trisyllabic forms such as /CuCuCu/, /CuCuCuC/, /CuCəCu/, /CuCə̆CuC/, and /CuCəCəC/ could potentially support the acoustic result from disyllabic words. In particular, vowels in the penult and ultima are the focus in trisyllabic words because it is reported that stress never falls on the antepenultimate syllable (Chen 2009b, Yeh 2011). If the influences of position and syllable type were factored out, the schwa in the penultimate position of the forms /CuCəCu/, /CuCəCuC/, and /CuCəCəC/ should be acoustically different from the schwa in the ultimate position of the form /CuCəCəC/. Finally, the [u] in the penultimate position of the forms /CuCuCu/ and /CuCuCuC/ should be acoustically similar to the [u] in the ultimate position of the forms /CuCəCu/ and /CuCəCuC/.

3.3.3 Experiment design

Two experiments were conducted to determine the stress pattern of Piuma Paiwan. The first one employed native words, whereas the second one used wug words. The primary purpose of the second experiment was to test the productivity of stress assignment (Berko 1958).

For the native word experiment, a word-list was constructed by consulting with two native speakers of Paiwan (see Appendix A). Disyllabic words of the shape /CuCu/,

/CuCuC/, /CəCu/, /CəCuC/, /CəCəC/, and /CuCəC/ were the focus in this experiment. Words of the shape /CuCu/ and /CuCuC/ were used to establish baselines for the acoustic realization of stressed and unstressed vowels. Crucially, other word types /CəCu/, /CəCuC/, and /CəCəC/ were used to verify the claim that stress avoids schwa in Piuma Paiwan since those words have schwa in penultimate position.

On consulting with native speakers, it was found that the total number of words with [u] in their lexicons was greater than that of words with [i] and [a]. So, words with the vowel [u] were the main focus in this study. The pairs allowed direct comparison of vowels in both putatively stressed and unstressed states. In addition, one quadrisyllabic and three trisyllabic words were included in the experiment so as to further confirm the results from disyllabic words, especially for F0. All the quadrisyllabic and trisyllabic words had identical vowels.

For disyllabic words, the first consonants were limited to [p, t, k, ts, q, s, l, ʎ, ɟ, v], while the second consonants were [p, t, k, ts, q, s, l, c, b, d, g]. For words with a coda in the second syllable, the consonants included [p, t, k, ts, q, s, c, ʎ, d, z]. All the consonants were unaspirated in order to reduce influence on the following vowel's duration (van Santen 1992: 527-532). The majority of the consonants were voiceless in order to keep influence on the preceding vowel's duration relatively constant (Peterson & Lehiste 1960). This stimulus structure not only facilitated identification of vowel boundaries but also minimized segmental effects on vowels (e.g. vowel lengthening before voiced consonants).

There were 7 stimuli for words with the [Cu.Cu] shape, 7 stimuli for words with the [Cu.CuC] shape, 11 stimuli for words with the [Cə.Cu] shape, 6 stimuli for words with the [Cə.CuC] shape, 11 stimuli for words with the [Cə.CəC] shape, and 8 stimuli for words

with the [Cu.CəC] shape. In sum, there were 50 stimuli in the experiment. No description

provides information on word frequency in vernacular words. However, the subjects who

helped me compile the list reported that the words were all familiar to them and frequently

used in everyday conversation. Loanwords from Mandarin and Japanese were excluded

entirely.

Morphologically, Piuma Paiwan is an agglutinative language. Some of the

trisyllabic words were composed of two morphemes instead of one, e.g. [ki-tətsək] 'go +

needle' and [tətsək-u] 'needle + imperative marker (exclusive)'. Although Yen (2011: 113)

reports that suffixes may attract stress from the default position due to vowel coalescence

or glide formation (see section 3.3.1), such cases were excluded from this study. All

disyllabic words were composed of one morpheme. Words with different parts-of-speech

were used in the experiment, including nouns, verbs, and adjectives. Recall that Chen (2004:

36) observed that syntactic classes do not affect stress assignment in Piuma Paiwan.

For the wug word experiment, a list of disyllabic and trisyllabic words was created

by the author (see Appendix B). Disyllabic words had the forms /CuCu/, /CuCuC/, /CəCu/,

/CəCuC/, /CuCəC/, and /CəCəC/. Trisyllabic words had the forms /CuCuCu/, /CuCuCuC/,

/CuCəCu/, /CuCəCuC/, and /CuCəCəC/. Note that schwa does not appear in absolute word-

final position, so closed syllables were included in the stimuli. The vowel [u] was chosen

for the stimuli because more words with [u] were found than words with [a] and [i] (see

discussion on the first experiment).

Onset segments were limited to unaspirated stops [p, t, d, k, g] on the first syllable,

and unaspirated voiceless stops [p, t, k] on the second and third syllables. The purpose of

using unaspirated voiceless stops was the same as mentioned in the experiment design for

native words. Note that two words had [d] and [g] in the initial onset ([deku] and [getu]) because the voiceless counterparts for both words are native words in Piuma Paiwan. Other words all had voiceless unaspirated stops in that position. Moreover, the consonant following schwa was the coronal stop [t] in almost all of the stimuli so as to avoid the influence of different places of articulation on the preceding schwa's quality.

Finally, there is no description of word shape frequency and vowel frequency in Paiwan. However, all my participants reported that they felt that the wug words were similar to native words. Techniques used to avoid potential unfamiliarity of wug words during the experiment are described in the discussion on experimental procedure in section 3.3.5.

Each word was placed within two frame sentences. To control for phrase-final lengthening, target words were placed in sentence-medial position, as shown in (15). It was found that there were different pauses in the frame sentences: a pause before the target word in (15a) and a pause after the target word in (15b). From now on, frame sentence (15a) will be called the 'post-pausal' context, and (15b) will be called the 'pre-pausal' context. We will see that pause (or phrase-finality) affects the acoustic realization of the final vowel (particularly in duration).

(15)   Two frame sentences (in Roman letters*)*

    a. Post-pausal sentence

       A   kai   na   paivan zuku   ____   aya.

       particle language paricle Paiwan race   say

       'This word is ____ in Paiwan.'

b. Pre-pausal sentence

Makaya ____ a si patjenema.

able particle this describe

'This word ____ can be described like this.'

There were three recording sessions for each experiment. For the native word experiment, participants read 54 stimuli (50 disyllabic words + three trisyllabic words + one quadrisyllabic word) and 5 fillers in each session. For the wug word experiment, participants read 47 stimuli and 9 fillers in each session. Colloquial filler sentences were employed to encourage the subjects to speak in their vernacular speech style. In particular, several fillers were thrown out at the beginning of each session to take into account the effects of any initial nervousness the subject might have about the task. Fillers were common words in Piuma Paiwan, such as animal names, kindship terms, and body parts. For both experiments, the order of the stimuli was pseudo-randomized and counter-balanced in each session. In sum, each participant produced 324 tokens for the native word experiment (54 stimuli × two frame sentences × three repetitions), and 282 tokens for the wug word experiment (47 stimuli × two frame sentences × three repetitions).

3.3.4 Participants

Two female native Piuma Paiwan speakers participated in the experiment.[1] One was 59 years old and the other was 48 years old at the time of recording. All had lived in Pinghe

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[1] One additional female participant was recorded in this experiment. However, the participant was

Village for more than 40 years, and grew up speaking Piuma Paiwan. All participants spoke Piuma Paiwan and Taiwan Mandarin, but still communicated in Piuma Paiwan on a daily basis in Pinghe Village. All participants were able to read both Mandarin characters and Paiwan Roman letters developed by the Council of Indigenous Peoples. None of the participants had formal linguistic training or a history of speech impairments. They were naïve as to the goal of the experiment. The participants received nominal monetary compensation for their participation.

3.3.5 Procedure

The experiments were performed at Pinghe Village in Pingtung County, Taiwan in the summer of 2016 by the author. Participants were recorded while sitting in a quiet room, wearing an AKG C420 head-worn microphone with behind-the-neck headband in order to keep the microphone at a constant distance from the mouth (thereby limiting inadvertent intensity variation). The recording was done using a Marantz PMD 670 at a 44.1k Hz sampling rate and 16-bit quantizing rate in mono.

Prior to the experiment, participants were asked when they felt at their best – i.e. when they felt most alert and awake. The experiment sessions were schedule based on their reports. Participants were asked to keep their usual daily routines for the day before the experiment.

For the experiment on native words, participants were presented with words written in both Roman letters and Mandarin characters on a computer screen. Participants were presented with some of the target words on screen before the recording sessions began. The

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inconsistent and hyper-articulated during the experiment, so her data were not analyzed.

goal was to familiarize them with the letters and characters since Piuma Paiwan does not have its own writing system. Target words were presented individually without frame sentences; that is, participants had to generate the two predetermined sentences from memory during the experiment. The recording sessions were conducted individually. Participants read the words when they were ready, at a normal conversational speed. Breaks were given after each recording session. Some effort was expended in ensuring that the subjects employed their vernacular. Specifically, the author engaged the participants in vernacular speech by having conversations with them during the breaks about Paiwan culture and mundane daily activities. The author specifically asked the participants how to say certain words in Piuma Paiwan, though the author is not a native speaker of Paiwan. The goal was to ensure that the speech was generated using the participants' vernacular L1 phonological modules (de Lacy 2014: 13-16).

For the experiment on wug words, participants were told a story about the head of the Pinghe tribe. The story went that one day the head of the Pinghe tribe discovered many new animal species in the field. The head then tried to name the new species. These new names were the stimuli of the experiment. Participants were asked to judge whether these new names were native words in Paiwan after producing the two frame sentences. Fillers were native animal names in Piuma Paiwan. Participants received a training session to familiarize themselves with the task; the purpose was to avoid potential unfamiliarity of the wug words. All the participants were able to distinguish wug words (stimuli) from native words (fillers). Unlike the experiment on native words, participants were presented with words only written in Roman letters on a computer screen. The rest of the experimental procedure was similar to the experiment on native words. Recording sessions

were conducted individually. Participants read the words when they were ready, at a normal conversational speed. Breaks were given after each recording session. The author also engaged the participants in vernacular speech, using the same technique applied in the experiment on native words.

To avoid participant exhaustion, participants completed the experiments over two different days. They all finished the experiment on native words on the first day and the experiment on wug words on the second day. The experiment was structured so that the potential effect of intra-speaker differences in separate sessions was minimized.

3.3.6 Measurements

Acoustic correlates of stressed/unstressed vowels were measured, including duration, F0, F1, F2, and intensity; measurements of spectral tilt are still in progress. Vowels were labeled using Praat TextGrids (Boersma & Weenink 2016). For disyllabic words, four intervals were labeled for each file: the extent of the first and second vowels of the target word in the two frame sentences. For trisyllabic words, six intervals were labeled for each file: the extent of the first, second, and third vowels of the target word in the two frame sentences. For the quadrisyllabic word, eight intervals were labeled.\

The left boundary of each vowel was marked at the beginning of the first non-deformed periodic waveform. The right boundary was identified as the end of the second formant, with the help of the third formant when the end of the second formant continued into closure (Turk *et al*. 2006: 7). For the experiment on native words, segmentation was performed by the author and a well-trained graduate student. The graduate student performed the segmentation for two repetitions from one speaker, and the author finished

the rest of the repetitions. For the experiment on wug words, the segmentation was solely performed by the author. All audio files and TextGrids were further double-checked by the author and the graduate student after the segmentation was finished with the goal of minimizing human error. Finally, the author examined the TextGrids and made corrections only when (a) wrong vowels were labeled, (b) consonants were mislabeled as part of a vowel, and (c) the right boundary of vowels was noted by the graduate assistant as uncertain; otherwise no changes were made. The labeled sound files were then run through customized Praat scripts to obtain acoustic measures. Duration and mean intensity were extracted from the TextGrids. For F0, F1, and F2, the midpoint of each vowel was calculated. The purpose was to identify the steady point of the vowel. The results were then saved to a Microsoft Excel (.xlsx) file for subsequent analysis, though they were analyzed in R (R Development Core Team 2016).

3.3.7 Statistical methods

In the following sections, I determine whether each of the acoustic measures was a statistically significant correlate of stress of [u] and schwa in Piuma Paiwan. The values of each measure were analyzed using linear mixed-effects models. These were implemented in R (R Development Core Team 2016) using the *lmer()* function of the *lme4* package (Bates *et al*. 2015). For each vowel ([u] and [ə]), five separate models were fit to determine the acoustic correlates of Piuma Paiwan stress. The acoustic measures (duration, F0, F1, F2, intensity) were the dependent variable. For each model, the vowel in different positions (e.g. [u1], [u2], [u3], [u4], [u5], [u6], [u7]) and frame sentences (i.e. post-pausal sentence, pre-pausal sentence) were set as fixed effects. Individual word was included as a random

effect. Interaction between the fixed effects (vowel positions and frame sentences) was tested in the model by using the *anova()* function to compare likelihood between models (Baayen 2008). Random slopes for the by-word effects of vowel positions and frame sentences were specified for each model (Barr *et al*. 2013).

For the F0, F1, F2, and intensity models on [u] and [ə], the interaction term was not found to significantly improve model fit, with all p-values greater than 0.196. For the duration models on [u] and [ə], the interaction term was found to significantly improve model fit. As for the random slope structure, all the models except for the intensity model on [u] failed to converge. So, the next best models were chosen based on the likelihood ratio test mentioned above. All of them included by-word random slope for the effect of frame sentences, not the effect of vowel positions. Visual inspection of residual plots did not reveal any obvious deviations from homoscedasticity or normality. Crucially, I report multiple pairwise comparisons for each vowel, which is obtained using the *pairwise()* function of the *lsmeans* package (Lenth 2016). These estimates were based on the Tukey Honestly Significant Difference (Tukey HSD) method. I report t-values as well as p-values provided in the model output. When the interaction term is not significant for the model (namely, the vowel does not behave differently in different frame sentences), I report multiple pairwise comparisons for both frame sentences.

3.3.8 Predicted prosodic patterns

Following the previous descriptions, and assuming that stress is realized by at least some acoustic property, the present proposal makes clear predictions about the acoustic realization of [u] and [ə] in various syllable positions. These predictions are summarized

in formulaic terms below. Here '$[\![x]\!]=[\![y]\!]$' means that the acoustic realization of $[\![x]\!]$ and $[\![y]\!]$ is predicted to be the same for stress-related acoustic cues, disregarding other potential influences; '$\neq$' means 'is predicted to be different'.

(16)   Native words

Phonological Input	→	Phonological Output	→	Phonetic Form	Acoustic stress predictions
a. /Cu$_1$Cu$_2$/	→	[(Cú$_1^\mu$.Cu$_2^\mu$)]	→	[$['$Cu$_1$Cu$_2$]$]	
b. /Cu$_3$Cu$_4$C/	→	[(Cú$_3^\mu$.Cu$_4^\mu$C)]	→	[$['$Cu$_3$CuC$_4$]$]	{$[\![u_1]\!]=[\![u_3]\!]=[\![u_5]\!]=$ $[\![u_6]\!]=[\![u_7]\!]$}$\neq$
c. /Cə$_1$Cu$_5$/	→	[C^{ə1}(Cú$_5^{\mu\mu}$)]	→	[$[$Cɜ$_1'$Cuː$_5$]$]	{$[\![u_2]\!]=[\![u_4]\!]$}
d. /Cə$_2$Cu$_6$C/	→	[C^{ə2}(Cú$_6^{\mu\mu}$C)]	→	[$[$Cɜ$_2'$Cuː$_6$C]$]	{$[\![ə_1]\!]=[\![ə_2]\!]=[\![ə_3]\!]=$ $[\![ə_5]\!]$}
e. /Cə$_3$Cə$_4$C/	→	[C^{ə3}(Cə́$_4^{\mu\mu}$C)]	→	[$[$Cɜ$_3'$Cəː$_4$C]$]	$\neq[\![ə_4]\!]$
f. /Cu$_7$Cə$_5$C/	→	[(Cú$_7^\mu$.Cə$_5^\mu$C)]	→	[$['$Cu$_7$Cə$_5$C]$]	

3.4 Results

This section presents results from both experiments on schwa's stress repulsion in Piuma Paiwan. Sections 3.4.1, 3.4.2, 3.4.3, 3.4.4, and 3.4.5 present results for F0, duration, intensity, F1/F2, and wug words, respectively. Recall from section 3.3.1 that predictions are made about [u]s and schwas in different positions. I will refer to the schema, repeated below, throughout the following discussion for native words.

(17)   The new hypothesis

Phonological	$\rightarrow$	Phonological	$\rightarrow$	Phonetic
Input		Output		Form
a. /Cu_1Cu_2/	$\rightarrow$	[($Cú_1{}^{\mu}.Cu_2{}^{\mu}$)]	$\rightarrow$	⟦$'Cu_1Cu_2$⟧
b. /Cu_3Cu_4C/	$\rightarrow$	[($Cú_3{}^{\mu}.Cu_4{}^{\mu}C$)]	$\rightarrow$	⟦$'Cu_3CuC_4$⟧
c. /$Cə_1Cu_5$/	$\rightarrow$	[$C^{ə1}(Cú_5{}^{\mu\mu})$]	$\rightarrow$	⟦$Cə̆_1{}'Cu{:}_5$⟧
d. /$Cə_2Cu_6C$/	$\rightarrow$	[$C^{ə2}(Cú_6{}^{\mu\mu}C)$]	$\rightarrow$	⟦$Cə̆_2{}'Cu{:}_6C$⟧
e. /$Cə_3Cə_4C$/	$\rightarrow$	[$C^{ə3}(Cə́_4{}^{\mu\mu}C)$]	$\rightarrow$	⟦$Cə̆_3{}'Cə{:}_4C$⟧
f. /$Cu_7Cə_5C$/	$\rightarrow$	[($Cú_7{}^{\mu}.Cə_5{}^{\mu}C$)]	$\rightarrow$	⟦$'Cu_7Cə_5C$⟧

3.4.1 F0

F0 provides clear evidence for stress placement in Piuma Paiwan. This was expected given previous descriptions that F0 is the only (or primary) acoustic correlate of stress in the language (Chen 2009b, Yeh 2011). \

Stressed vowels were predicted to have higher F0 than unstressed ones: for words with default (i.e. penultimate) stress, vowels in the penult should have a higher F0 than vowels in the ultima. However, if the penult contains a schwa, vowels in the ultima should be stressed and thus have a higher pitch than vowels in the penult.

• *F0 in disyllabic words with putative penultimate stress*

Speech rate and pitch range varied from speaker to speaker, so they were accounted for by

normalizing actual time and F0 contours using the Prosody Pro script for Praat (Xu 2013).[2]

The mean normalized F0 contours for each stimulus are presented below.
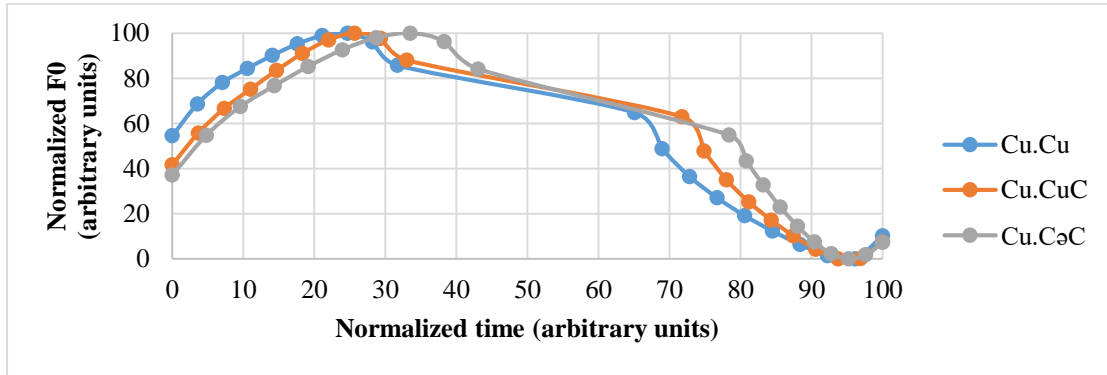
Figure 3.1: Intonation on [Cu.Cu], [Cu.CuC], and [Cu.CəC] in the first repetition.
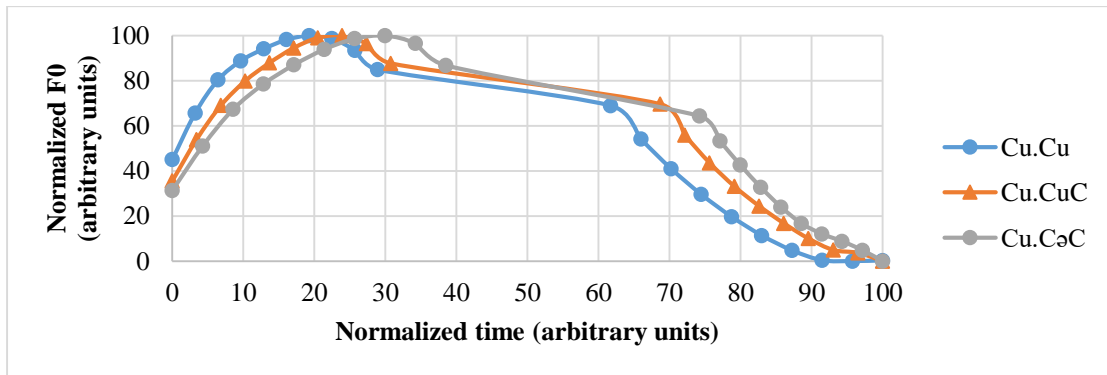
Figure 3.2: Intonation on [Cu.Cu], [Cu.CuC], and [Cu.CəC] in the second repetition.

Figures 3.1 and 3.2 show the F0 contours for default penultimate stress. In both figures, the dotted parts indicate the normalized pitch track of the two target vowels. The straight line connecting both vowels represents the onset consonant (i.e. its closure and

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[2] The F0 contours and actual time were normalized with each interval divided into ten points. There are 20 points for each word since there are two vowels. First, the time of each point across all words in the same shape was averaged. The difference between each point and the starting point was divided by the difference between the starting and end points. The results were then multiplied by 100 to turn them into percentages. As for F0, the F0 of each point across all words in the same shape was averaged. The difference between each F0 point and the minimum F0 point was divided by the difference between the maximum and minimum F0 points. The results were then multiplied by 100 to turn them into percentages.

burst) in the second syllable. For words with the forms [Cu.Cu], [Cu.CuC], and [Cu.CəC], the vowel in the penult has a significantly higher pitch than the vowel in the ultima ($p<0.01$). The result is consistent with Chen (2009b)'s and Yeh (2011)'s studies.

• *Light CVC syllables*

The F0 contours also provide crucial evidence that closed syllables do not influence stress in Piuma Paiwan. If CVC syllables were heavy and heavy syllables attract stress, then stress should fall on the ultimate syllable in words like [Cu.CuC] and [Cu.CəC], and so the ultima should have a higher F0 than the penult. However, the vowel in the penult in both [Cu.CuC] and [Cu.CəC] in fact has a higher pitch than the ultima ($p<0.001$), refuting the hypothesis that coda consonants are weight-bearing and therefore attract stress.

• *F0 in trisyllabic and quadrisyllabic words with putative penultimate stress*

The F0 contours from trisyllabic and quadrisyllabic words also support the claim that the default stress position is on the penultimate syllable, rather than the antepenultimate or initial syllable. The trisyllabic and quadrisyllabic word F0 patterns are provided below. The graphs show that the vowel in the penult has a higher F0 than the vowels in the antepenultimate and initial syllables ($p<0.001$). The graphs show F0 contours for both frame 1 (in blue) and frame 2 (in orange). The beginning and end of the penultimate syllable is marked with black vertical lines.
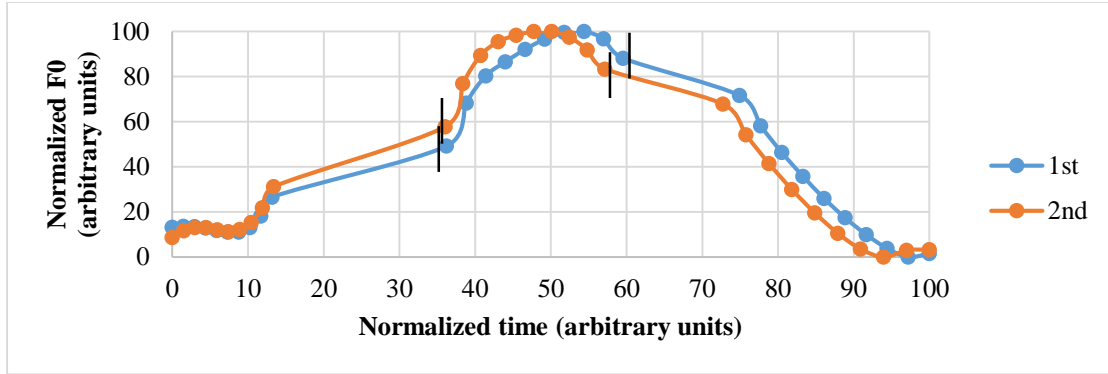
Figure 3.3: Intonation on [CV.CV.CV] in both repetitions.
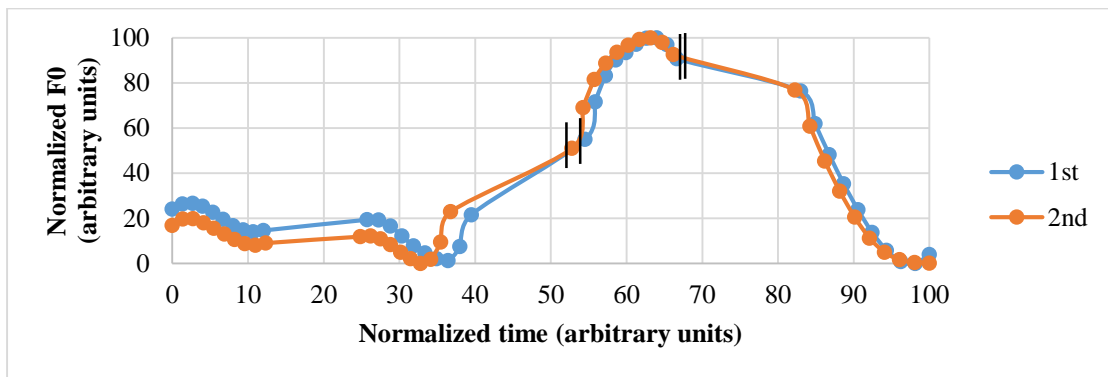
Figure 3.4: Intonation on [CV.CV.CV.CV] in both repetitions.

- *Words with putative final stress*

Crucially, for words of the form [Cə.Cu], [Cə.CuC], and [Cə.CəC], the vowel in the ultima was found to have a significantly higher F0 than the vowel in the penult ($p<0.01$).
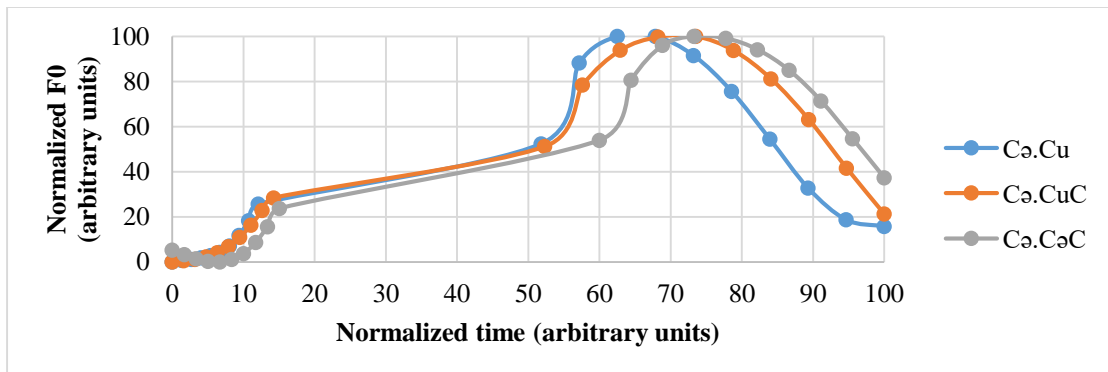
Figure 3.5: Intonation on [Cə.Cu], [Cə.CuC], and [Cə.CəC] in the first repetition.
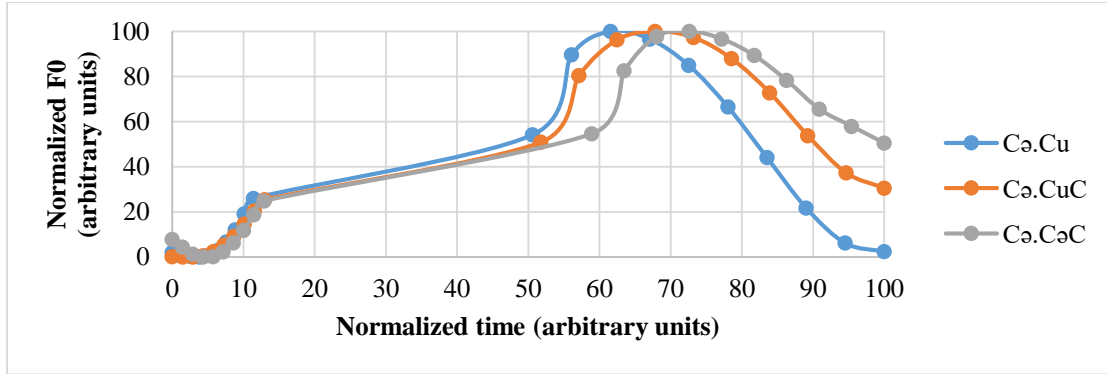
Figure 3.6: Intonation on [Cə.Cu], [Cə.CuC], and [Cə.CəC] in the second repetition.

The fact that the final syllable has a higher F0 cannot be attributed to syllable weight (i.e. the idea that CVC is heavy in these words): syllable weight does not explain why the final vowel in [Cə.Cu] has higher F0 than the penult as both syllables are open.

• *Perceptibility*

Fry (1958) conducted three experiments to test the effect of changes in three acoustic properties on stress judgments: duration, intensity and fundamental frequency. Fry found that, of the features associated with stress, higher F0 was perceptually the most important in determining perceived prominence.

For P, F0 over stressed syllables was perceptually significantly higher than that over unstressed syllables. For example, u1 and u2 in [Cu1Cu2] have the F0 means 234Hz (s.d.=46Hz) and 170Hz (s.d.=13Hz), respectively. The lower bound (1SD) for u1 is 188Hz, whereas the upper bound (1SD) for u2 is 183Hz. So, 68% of the data from u1 and u2 do not overlap with each other. Similarly, ə3 and ə4 in [Cə3Cə4C] have the F0 means 163Hz (s.d.=11Hz) and 244Hz (s.d.=30Hz), respectively. The upper bound for ə3 (1SD) is 174Hz while the lower bound (1SD) for ə4 is 214Hz. Therefore, 68% of the data from ə3 and ə4 do not overlap with each other. The same analysis applies to u3 and u4 in [Cu3Cu4C], in

which u3 and u4 have the F0 means of 241 Hz (s.d.=45Hz) and 179 (s.d.=14Hz), respectively.

In summary, the F0 result is consistent with Chen (2009b)'s and Yeh (2011)'s descriptions. Although previous studies do not provide systematic measurements of the F0 pattern of words with schwa, this study fills the gap and strengthens the claim that F0 does play an important role in stress assignment in Piuma Paiwan. I conclude, according with Chen (2009b) and Yeh (2011), that Piuma Paiwan uses F0 as a cue for stress.

The remaining question is whether F0 is a direct realization of metrical headedness, or whether it is the high tone of an intonational tune that docks onto metrical heads. This issue could be resolved by an in-depth study of the intonation of the language; unfortunately, that is beyond the scope of the present study.

3.4.2 Duration

This section addresses two questions. One is whether duration is an acoustic correlate of stress in Piuma Paiwan. This is a reasonable question because stressed syllables are longer than unstressed ones in some languages (e.g. Tongan – Garellek & White 2012). However, this section concludes that stress is not realized by enhancing duration – all variation in duration can be ascribed to other phonetic and phonological processes (cf. Chen 2004, 2009b).

The second question is whether the duration patterns accord with the hypothesis outlined in previous sections. The present hypothesis claims that u6 and u7 are both bimoraic, and so should have longer duration than all other u's, all else being equal. Further, ə4 is predicted to be bimoraic, and so should be longer than ə5, which should be longer

than all of the non-moraic schwas (ə1, ə2, ə3).

In contrast, the previous descriptions do not claim that there is any difference in moraicity between [u]s and [ə]s. So, it claims that all [u]s should have the same duration, and all [ə]s should have the same duration.

(18)   Predictions for duration

a. Present hypothesis

(i) $\{u_5, u_6\}$ > all other u's

(ii) $ə_4 > ə_5$ > all other ə's

b. Previous descriptions

(i) All [u]s have the same duration

(ii) All [ə]s have the same duration

One complication is that mora count is not the only influence on vowel duration in Piuma Paiwan. To evaluate the moraic influences on duration – and the influence of headedness/stress – requires a model of all the factors that influence duration in the stimuli.

• *A model of vowel duration in Piuma Paiwan*

There are four determinants of vowel duration in the tokens: bimoraicity, PrWd-final lengthening (pfl), Frame 1 Penult Lengthening (f1pl), closed syllable shortening (css), and bimoraicity ($\mu\mu$). I propose a multiplicative model, in the spirit of Klatt (1976).

(19)   Piuma Paiwan vowel duration model

$Vdur = D_{inh} \times \mu\mu \times f1pl \times pfl \times css$

The model says that a particular vowel's duration is determined by its inherent vowel duration (D_{inh}), multiplied by its bimoraicity value, f1pl value, pfl value and css value. For environments where a multiplier does not apply, the multiplier is 1.

Importantly, the duration model does *not* include a stress multiplier. In other words, the model claims that stress does not cause any change in duration. So, all of the factors above are entirely adequate in accounting for duration.

PrWd-final lengthening (pfl) refers to lengthening of the final syllable of a PrWd. Such lengthening is reported by (Chen 2004, 2009b), and is clearly observable when comparing the two vowels in [Cu_1Cu_2] tokens for frame 2: ⟦u_1⟧'s duration mean is 113ms, while ⟦u_2⟧'s is 151ms (p <0.0001). PrWd-final lengthening is taken here to increase the duration of a vowel by 34% (i.e. pfl=1.34), a value determined from dividing 151 into 113.

Frame 1 penult lengthening (f1pl) involves lengthening the penultimate vowel in Frame 1 sentences only. Exactly why the lengthening occurs is discussed below (section 3.4.2.3). This lengthening is clearly visible when comparing the same vowel in frames 1 and 2. For example, in ⟦Cu_1Cu_2⟧, u_1 has a mean of 141ms in frame 1 and 113ms in frame 2. Similarly, in ⟦Cu_3Cu_4C⟧, u_3 is 132ms in frame 1 and 116ms in frame 2. From these measurements, f1pl's value is approximated at 1.195.

Vowels in closed syllables are shorter than those in open syllables. For example, in ⟦Cu_1Cu_2⟧ and ⟦Cu_3Cu_4C⟧, u_2 has a mean duration of 156ms while u_4 is 115ms. There are multiple other comparisons that show css. Putting them together, css is taken to involve a

reduction of the vowel by multiplying 0.77.

Finally, having an extra mora should add extra length. Previous research has established that long vowels can differ from between 1.3 and 3 times a short vowel's length (e.g. in Dinka, long vowels are around 1.5 times longer than short vowels – Remijsen & Gilley 2008). In Piuma Paiwan, bimoraic vowels are around 1.425 times the duration of monomoraic vowels.

The duration model, and values of $\mu\mu$, pfl, f1pl, and css, can be applied to both [u] and [ə] in different environments to predict their duration. Each vowel will be discussed in turn.

3.4.2.1 [u]

The inherent duration of [u] in the tokens collected was discovered by examining u's in positions where none of the duration-modifying processes apply. In the second frame of ⟦Cu_1Cu_2⟧, for example, u_1 is 113ms long, and u_3 is 116ms long in ⟦Cu_3Cu_4C⟧. So, the inherent duration of [u^μ] is taken to be 114.5ms long.

The duration model predicts mean durations for all of the different [u]s. The predictions are compared to the actual durations below.

u=114.5	f1pl	pfl	bm	css	Predicted(ms)	Actual(ms)	Diff.(ms)
u1	1.195				137	141 (31)	-4.2 (-0.13)
u2		1.34			153	156 (25)	-2.6 (-0.12)
u3	1.195				137	132 (28)	4.8 (0.18)
u4		1.34		0.77	118	115 (20)	3.1 (0.15)
u5		1.34	1.425		219	214 (25)	4.6 (0.2)
u6		1.34	1.425	0.77	168	170 (23)	-1.6 (-0.09)
u7	1.195				137	143 (34)	-6.1 (-0.18)

Table 3.1: Predicted and actual durations of the various [u]s in frame sentence 1. Inherent duration of [u] is 114.5ms. Milliseconds are rounded. Difference is expressed in milliseconds and z-scores (in parentheses).

As an example, u6 is found in the stimulus /CəCu$_6$C/. The current hypothesis claims that it has the prosodic form [Cə(Cu$_6$$^{\mu\mu}$C)]. So, it should be subject to PrWd-final lengthening and closed-syllable shortening, and it is bimoraic. Consequently, its duration is predicted to be 114.5×1.34×1.425×0.77=168ms. The actual mean duration is 170ms. The difference between the predicted and actual durations is 1.6ms – i.e. very close to the actual result.

As can be seen from the predicted and actual measurements, the model and actual differences fit very closely ($\chi^2(6)$=0.4145, p=0.9987). The greatest difference is for u$_7$, which is predicted to have a duration of 137ms, but actually had a mean duration of 143ms (with a standard deviation of 34ms).

The crucial point of the proposal is that u$_5$ and u$_6$ are predicted to gain length by being bimoraic. The model and results show that this is indeed the case: u$_5$ and u$_6$ are the longest vowels in both frames. Notably, all comparisons of u$_5$ with all other vowels resulted in p-values of <0.0001.

Interestingly, u$_6$ is subject to closed syllable shortening. So, it is predicted to be shorter than u$_5$, which it is (p<0.0001). It is also predicted to be longer than most other vowels, which it is (p<0.0001 for u$_4$ and u$_5$, p=0.0017 for u$_3$, p=0.0263 for u$_1$). The only vowel that is predicted to approach it in duration is u$_2$, which is lengthened due to phrase-final lengthening and is not subject to closed-syllable shortening. Unsurprisingly, there is no significant difference between u$_2$ and u$_6$ (p=0.7083).

The model also predicts that there should be little difference between u$_1$, u$_3$, u$_4$, and u$_7$, and as predicted, there are no significant differences:

	u3	u4	u7
u1	0.9451	0.0641	1.000
u3		0.0157	0.8390
u4			0.270

Table 3.2: Comparisons between u1, u3, u4, and u7. No significant differences.

In fact, the duration model predicts exactly which differences between [u]s should be significant and which should not be/were unlikely to be, as shown in Table 3.3. As Table 3.3 shows, all differences predicted to be significantly different were significantly different (p<0.05), with the majority significant to p<0.01. All differences predicted to not be different, or marginally different, were not significantly different (except for u3 vs. u4 at p=0.0157).

	u2	u3	u4	u5	u6	u7
u1	0.213[3]	0.9451[2]	.0641[3]	<.0001[1]	0.0263[1]	1.000[2]
u2		0.0808[3]	0.0003[1]	<.0001[1]	0.7083[3]	0.6443[3]
u3			0.0157[3]	<.0001[1]	0.0017[1]	0.8390[2]
u4				<.0001[1]	<.0001[1]	0.270[3]
u5					<.0001[1]	<.0001[1]
u6						0.0404[1]

Table 3.3: P-values of frame 1 [u] comparisons. Cells with [1] were predicted by the model to be significantly different. Those marked with [2] were predicted to not be significantly different. Those with [3] were predicted to be likely to be marginal in their difference, given the number of tokens involved.

Similar observations can be made for frame 2. The difference between [u] in frames 1 and 2 is that f1pl does not apply to frame 2 vowels.

	f1pl	pfl	μμ	css	Prediction	Actual	Diff.
u1					115	113 (18)	1.5 (0.1)
u2		1.34			153	151 (20)	2.4 (0.1)
u3					115	116 (24)	-1.5 (-0.04)
u4		1.34		0.77	118	117 (17)	1.1 (0.05)
u5		1.34	1.425		219	202 (27)	16.6 (0.63)
u6		1.34	1.425	0.77	168	166 (25)	2.4 (0.08)
u7					115	120 (22)	-5.5 (0.23)

Table 3.4: Predicted and actual durations of the various [u]s in frame sentence 2. Inherent duration of [u] is 114.5ms. Milliseconds are rounded. Difference is expressed in milliseconds and z-scores (in parentheses).

Table 3.4 shows similar results for the second frame sentence ($\chi^2(6)=0.6812$, p=0.9949). The biggest difference is with u5 which is predicted to be slightly longer than it actually was.

The predicted differences for frame 2 are slightly different compared to frame 1. Again, u5 is predicted to be significantly longer than all other vowels, and this was the case (p<0.0001 for all vowel comparisons). Similarly, u6 is predicted to be significantly longer than all other vowels (p≤0.0001 for all vowels), except for u2 (p=0.4455). u1, u3, u4, and u7 are predicted to be indistinguishable in terms of length, and they were (all p-values for all u1/3/4/7 comparisons were >0.9725).

As Table 3.5 shows, all predicted differences were significantly different at the p<0.01 level, and all differences predicted to not be significant were not, with almost all p-values >0.97 (u_2 vs u_6 was not significant at p=0.4455).

	2	3	4	5	6	7
u1	$<0.0001^1$	0.9998^2	0.9985^2	$<0.0001^1$	$<0.0001^1$	0.9725^2
u2		0.0004^1	0.0006^1	$<0.0001^1$	0.4455^2	0.0012^1
u3			1.0^2	$<0.0001^1$	$<0.0001^1$	0.9983^2
u4				$<0.0001^1$	$<0.0001^1$	0.9998^2
u5					$<0.0001^1$	$<0.0001^1$
u6						$<0.0001^1$

Table 3.5: P-values of frame 2 [u] comparisons. Cells with [1] were predicted by the model to be significantly different. Those marked with [2] were predicted to not be significantly different.

In summary, the predicted duration model fits very well with the actual mean durations, and the predicted significant differences also fit with the actual significant differences. In short, the New hypothesis is borne out by the duration results for [u].

It is important to emphasize here that there is one important factor missing from the duration model: stress-conditioned lengthening. The durations here are entirely explained by closed syllable shortening, PrWd-final lengthening, bimoraicity, and frame 1 penult lengthening. There is no place for any lengthening due to stress. Therefore, stress is not realized as any duration increase in [u].

• *Comparison with previous descriptions*

Previous descriptions claim that all [u]s are monomoraic. So, the duration predictions for these vowels would be as follows, once f1pl, pfl and css are taken into account:

	f1pl	pfl	μμ	css	Prediction	Actual	Diff.
u1	1.195				137	141	-4.2
u2		1.34			153	156	-2.6
u3	1.195				137	132	4.8
u4		1.34		0.77	118	115	3.1
u5		**1.34**	*n/a*		**153**	**214**	**-60.6 (-2.44)**
u6		**1.34**	*n/a*	**0.77**	**118**	**170**	**-51.8 (-2.26)**
u7	1.195				137	143	-6.1

Table 3.6: Previous descriptions' predicted and actual durations for frame 1.

In other words, the previous descriptions predict that u_5 and u_6 should be much shorter than what they are, i.e. they should be 153ms and 118ms on average, which is over 50ms too short for both. For the present proposal, the extra duration is ascribed to bimoraicity. Overall, the traditional description's duration model has a much poorer fit to the actual results than the alternative model ($\chi(6)=13.0395$, p=0.04241 for frame 1).

In short, the extra duration seen in u_5 and u_6 clearly supports the present hypothesis, and does not fit the previous descriptions' hypothesis.

3.4.2.2 [ə]

The duration model developed above applies to [ə], too. The various ə's are restated below for the reader's convenience.

(20)   New hypothesis

a.	$C^{ə1}(C\acute{u}_5{}^{μμ})$
b.	$C^{ə2}(C\acute{u}_6{}^{μμ}C)$
c.	$C^{ə3}(C\acute{ə}_4{}^{μμ}C)$
d.	$(C\acute{u}_7{}^{μ}.Cə_5{}^{μ}C)$

The major difference between [u] and [ə] is that [ə] has a different inherent duration from [u]. The inherent duration here is calculated to be around 74ms. There is no monomoraic

[ə] that is unaffected by some other value, so the duration of [ə5] was taken to be indicative

of [ə]s inherent duration, taking into account pfl and css.

There is one further factor that is relevant to [ə] and not [u]: some [ə]s are predicted

to be non-moraic. The effect of being non-moraic is to shorten [ə] significantly. While the

present theory makes no particular predictions about exactly by *how* much a non-moraic

schwa is shorter than a monomoraic one, the degree of shortening was calculated to be

around 0.58 of the total vowel duration, calculated by averaging over frame 2's ə1, ə2, and

ə3 since they have no other duration influences. The 'nomora' column takes non-moraic

shortening into account.

	f1pl	pfl	nomora	μμ	css	Total	Actual	Diff.
ə1	1.195		0.58			51	53 (20)	-1.7 (-0.1)
ə2	1.195		0.58			51	51 (20)	0.2 (0)
ə3	1.195		0.58			51	50 (18)	1.2 (0.06)
ə4		1.34		1.425	0.77	109	134 (28)	-25.2 (-0.89)
ə5		1.34			0.77	76	72 (16)	4.4 (0.3)

Table 3.7: Predicted and actual durations for ə for frame 1

	f1pl	pfl	nomora	μμ	css	Total	Actual	Diff
ə1			0.58			43	46 (16)	-3.1 (-0.19)
ə2			0.58			43	44 (15)	-1.1 (-0.7)
ə3			0.58			43	42 (14)	0.9 (0.07)
ə4		1.34		1.425	0.77	109	137 (26)	-28.2 (-1.08)
ə5		1.34			0.77	76	80 (18)	-3.6 (-0.22)

Table 3.8: Predicted and actual durations for ə for frame 2

As Tables 3.7 and 3.8 show, the predicted durations for ə are a close fit to the actual

durations ($\chi^2(4)=2.0371$, p=0.7289 for frame 1, and $\chi^2(4)=1.5707$, p=0.8141 for frame 2).

In terms of predicted statistical differences, ə1, ə2, and ə3 are predicted to be the

same in both frames, and ə4 and ə5 are both predicted to be significantly different. These

predictions are borne out, as shown in Tables 3.9 and 3.10. In all cases, the differences predicted to be significantly different were so (p<0.0001), and the differences predicted to not be significant were not, with p ≥ 0.9964.

	2	3	4	5
1	0.9964^2	0.9969^2	$<0.0001^1$	$<0.0001^1$
2		1.0^2	$<0.0001^1$	$<0.0001^1$
3			$<0.0001^1$	$<0.0001^1$
4				$<0.0001^1$

Table 3.9: P-values for ə comparisons, frame 1. [1] marks predicted significance; [2] marks a prediction of non-significance.

	2	3	4	5
1	0.9980^2	0.9969^2	$<0.0001^1$	$<0.0001^1$
2		1.0^2	$<0.0001^1$	$<0.0001^1$
3			$<0.0001^1$	$<0.0001^1$
4				$<0.0001^1$

Table 3.10: P-values for ə comparisons, frame 2. [1] marks predicted significance; [2] marks a prediction of non-significance.

To summarize, what the results show is that there are three different types of [ə] in terms of duration: (1) the 'overshort' ə's, around 50ms long, (2) the short ə5, around 70-80ms long, and (3) the long schwa (ə4), around 135ms long. The differences between ə4, ə5, and ə1, ə2, and ə3 are highly significant.

The current hypothesis predicts exactly the duration results above. Most importantly, it predicts that (a) ə4 will be the longest because it is bimoraic, (b) ə5 will be the next longest because it is monomoraic, and (c) ə1/2/3 will be shortest because they are non-moraic.

In contrast, the traditional descriptions predict that all schwas in open syllables should be longer than those in closed syllables (due to closed-syllable shortening), but

otherwise they should have similar durations. In other words, taking css into account, previous descriptions predict that ə1, ə2, and ə3 should be longer than ə4 and ə5. As seen above, this prediction does not fit with the results: ə4 and ə5 are longer than ə1/2/3, and ə4 and ə5 have significantly different durations.

In more straightforward terms, the traditional description fails to predict that ə4 is longer than ə5 – they should both have one mora, so there should be no duration difference between them.

3.4.2.3 Stress and duration

The duration model presented above does not accommodate a stress-conditioned duration increase. In other words, the model above claims that stress does *not* influence duration in Piuma Paiwan.

If stress influenced duration, stressed [u]s should be longer than unstressed ones, with all else held constant (i.e. pfl, f1pl, css, $\mu\mu$). Unfortunately, there is no way to straightforwardly compare [u]s because there are no stressed~unstressed [u] pairs that differ only in stress: all unstressed [u]s are in final syllables, and so all are subject to final lengthening. The only final stressed syllable is bimoraic, so it cannot be directly compared here, either. The same issue arises for schwa. The only stressed schwa is bimoraic, and all others are monomoraic or non-moraic.

However, the other influences – i.e. pfl, f1pl, css, $\mu\mu$ – can be pared away. When they are, there is no place for any stress-conditioned duration increase. For example, frame 2's u1, u3, and u7 are all unaffected by f1pl, pfl, $\mu\mu$, and css, but have the same duration as [u]'s inherent duration. If stress added duration, the stressed u1, u3, and u7 should all

be longer than the unstressed u4, since u4's closed syllable shortening effectively cancels out its gains from PrWd-final lengthening. However, u1, u3, u7, and u4 all have durations that do not differ in statistical significance.

Similarly, if stress increases vowel duration, the stressed ə (ə4) should be longer than what it is. Even though ə4 is the longest of schwas at over 130ms, all its length is explained by the fact that it is PrWd-final, bimoraic, and undergoes closed syllable shortening.

In that regard, the most significant deviation from predicted durations was the actual duration of ə4. For both frames, the model predicted that ə4 should be around 109ms on average. However, it was actually 134ms long. This is also the only situation in which schwa is stressed. In other words, it is possible that stress adds around 25% more duration to schwa. Unfortunately, a problem with this proposal is that other stressed vowels do not lengthen. For example, stressed [u]s are not 25% longer than predicted in the model that lacks stress-conditioned lengthening (see Table 3.1 and Table 3.4). Even word-final stressed [u]s are not 25% longer than predicted: u_5 is predicted to be 219ms long, but is actually shorter (214ms in frame 1 and 202ms in frame 2). Consequently, one would have to argue that *only* schwa lengthens because of stress.

It is quite possible that the difference in ə4's predicted and actual durations is due to variability in long vowel duration. Long vowels are known to have greater variation in their durations than short vowels, and so the differences seen for the predicted and actual durations of ə4 and u5 may be simply due to their bimoraicity.

• *Frame 1 penultimate lengthening*

f1pl is not lengthening due to PrWd-level stress. If it was, then such lengthening should apply in frame 2 as well. f1pl is also not lengthening of all stressed vowels in frame 1; otherwise, u5 and u6 would be much longer (i.e. 261ms and 201ms respectively) than they actually were (214ms and 170ms).

The duration model has f1pl applying to the penultimate unstressed vowels ə1, ə2, and ə3. The model in which f1pl applies fits well to the data ($\chi^2=0.1$), while the model without f1pl does not ($\chi^2=0.025$). In other words, f1pl is required to make the model fit.

So, what is f1pl if it is not stress-related? In frame 1, the target word is post-pausal – i.e. phrase-initial. So, it is possible that f1pl is actually phrase-initial fortition (e.g. Cho & Keating 2009). In any case, f1pl is clearly not stress-related lengthening, and therefore is irrelevant to the results presented here.

In short, once all duration effects are taken into account, the results are consistent with the hypothesis proposed here, and not the previous descriptions.

3.4.3 Intensity

This section shows that intensity is influenced by two factors: stress and syllable type (open vs. closed). Stressed vowels are more intense than unstressed vowels, and vowels in closed syllables are more intense than vowels in open syllables.

3.4.3.1 Stress

Intensity is boosted for stressed vowels.

The effect is clearly seen in [Cú$_1$Cu$_2$] and [Cú$_3$Cu$_4$C] where u1 is more intense than

u2 (t=−11.309, p<0.0001) and u3 is more intense than u4 (t=−4.548, p=0.0002). Here and below, measurements from both frame sentences were pooled because a statistical analysis showed that there was no difference in intensity values between the two (see section 3.3.7).

Comparison of u's in other positions also shows that stressed and unstressed u's are differentiated by intensity. Recall that u5, u6, and u7 are stressed. Comparing the unstressed u2 with u5, u6, and u7 reveals that there is a significant difference in terms of intensity, with all p-values <0.0092.

Intensity is also boosted for stressed schwa. In the one word type where both vowels are schwa (Cə3.Cə́:4C), ə3 at 62.3dB (3.2) is significantly less intense than ə4 (68.4dB (1.8)), with p<0.0001. It should be noted that comparing stressed and unstressed schwa *across* different frames does not reveal a statistically significant difference (ə4 (68.4dB) vs. ə5 (66.2dB): p=0.1999). However, it could be that there were not enough tokens to make the difference robust, so it is still possible that stressed schwas are more intense than unstressed ones.

The finding that intensity distinguishes stressed and unstressed syllables accords with Ferrell (1982)'s study on another Paiwan dialect.

3.4.3.2 Closed syllables

The intensity of vowels in closed syllables is boosted, too. For example, u2 and u4 are both unstressed. However, u2 is in an open syllable and so is less intense than u4, which is in a closed syllable (u2=62.5 (2.3), u4=64.7 (2.3), p=0.0247).

Similarly, u5 and u6 are both stressed. However, u5 is in an open syllable while u6 is in a closed syllable, with different intensities resulting (u5=65dB (2.1) vs. u6=66.5dB

(1.9), p=0.0046).

Finally, in [Cú7.Cə5C], ə5 is unstressed but in a closed syllable, so it has a boosted intensity (66.2dB (2.2)) relative to other the unstressed schwas ə1 (p=0.0002) and ə3 (p=0.0019). However, it is unexpected that ə2 and ə5 are not significantly different (p=0.1511).

3.4.3.3 Stress and closed syllables

While the vowels u4 and ə5 are both unstressed, they are in closed syllables, so their intensity is boosted. The intensity boost means that they end up with an intensity similar to that of stressed vowels.

So, the intensity of u4 is not significantly different from those of the stressed vowels u5, u6, and u7 (all comparisons have p>0.05), though there is a difference compared to u3 – i.e. the other vowel in u4's stimulus shape (p=0.0002).

Similarly, ə5's intensity is boosted, averaging 66.2dB (2.2). This is not significantly different from the stressed ə4's (p=0.1999).

It is not clear that intensity is additive. If it were, one might expect stressed closed syllables to be more intense than stressed open syllables. This is indeed the case for u6 vs. u5, as noted above. However, u6 is not significantly different from u1, u2, or u3. Also, while ə4 and ə5 have different means (ə4=68.4dB, ə5=66.2dB), the difference is not statistically significant (p=0.1999).

3.4.3.4 Overall intensity effects

The overall effect of intensity, then, is that unstressed vowels in open syllables have low

intensity (u2, ə1, ə2, ə3), and vowels in stressed or closed syllables have higher intensity (u1, u3, u4, u5, u6, ə4, ə5).

The following tables summarize the intensity results for both vowels, and give statistical significance levels for comparisons. There are two places where the statistical results are unexplained – both are marked with *; they are discussed in the preceding sections.

Stimuli	Both frame sentences
Cú1.Cu2	u1: 65.9 (2.4), u2: 62.5 (2.3)
Cú3.Cu4C	u3: 66.1 (1.8), u4: 64.7 (2.3)
Cə.Cú:5	u5: 65 (2.1)
Cə.Cú:6C	u6: 66.5 (1.9)
Cú7.CəC	u7: 66.6 (2.6)

Table 3.11: Averaged intensity values (dB) of [u] vowels in both contexts.

	u2#	ú3	u4C#	ú:5#	ú:6C#	ú7
ú1	<0.0001	0.9981	0.6296	0.5891	0.9087	0.8784
u2#		0.0008	0.0247	0.0092	0.0003	0.0005
ú3			0.0002	0.2412	0.9980	0.9859
u4C#				0.9999	0.0597	0.1307
ú:5#					0.0046*	0.1017
ú:6C#						0.9992

Table 3.12: [u] intensities compared.

Stimuli	Both frame sentences
Cə1.Cú:	ə1: 61.7 (4.5)
Cə2.Cú:C	ə2: 63.4 (3.1)
Cə3.Cə́:4C	ə3: 62.3 (3.2), ə4: 68.4 (1.8)
Cú.Cə5C	ə5: 66.2 (2.2)

Table 3.13: Averaged intensity values (dB) of [ə] vowels in both contexts.

	ə2 (ᵊ)	ə3 (ᵊ)	ə4 (ə́ᵘᵘ)	ə5 (əC#)
ə1 (ᵊ)	0.2574	0.8856	<0.0001	0.0002
ə2 (ᵊ)		0.6986	0.0007	0.1511*
ə3 (ᵊ)			<0.0001	0.0019
ə4 (ə́ᵘᵘ)				0.1999

Table 3.14: Moraicity and intensity – comparison of p-values.

In conclusion, intensity is influenced by stress and syllable shape.

There is no evidence that intensity reflects raw duration. For example, u5 is the longest [u] (214ms in frame 1), and u7, u3, and u1 are significantly shorter at 132-143ms. However, there is no significant difference between u5's and u7's, u3's, or u1's intensity.

There is no clear evidence that intensity is reduced for non-moraic schwas. While non-moraic schwas (ə1, ə2, ə3) are less intense than moraic schwas (ə4, ə5), both ə4 and ə5 are in closed syllables and so should have a higher intensity regardless. Notably, non-moraic schwas have the same intensity as unstressed monomoraic [u] (i.e. ə1=61.7, ə2=66.5, ə3=62.3, and u2=62.5dB), so it is difficult to maintain that lack of moras results in lower intensity.

3.4.4 F1 and F2

This section presents the results for vowel quality – i.e. F1 and F2. For [u], no evidence was found that stress affects vowel quality. For [ə], there is weak evidence that stressed ə is lower than unstressed ə.

However, there are clear results relating to the variability of schwa. While the quality of schwa is highly influenced by surrounding consonants, when schwa is moraic (i.e. ə4 and ə5), its F1 and F2 are much less influenced by the environment.

3.4.4.1 Means of [u]

Focusing on [u]'s F1, u2 has a significantly lower F1 than all other [u]'s. In articulatory

terms, u2 is higher than all the other vowels. However, this is the opposite of what one

would expect: unstressed vowels are typically more central than stressed ones, so u2 should

be lower than the stressed [u]s (i.e. u1/u3/u5/u6/u7). Other comparisons do not show any

significant differences at all; importantly, unstressed u4 has the same height as the stressed

[u]'s. So, it is not clear that stress conditions an F1 difference for [u]. At the very least,

F1 is not a robust cue of stress.

Stimuli	Both frame sentences
Cú1.Cu2	u1:413 (77), u2: 382 (32)
Cú3.Cu4C	u3: 439 (69), u4: 430 (43)
Cə.Cú:5	u5: 448 (49)
Cə.Cú:6C	u6: 462 (53)
Cú7.CəC	u7: 448 (64)

Table 3.15: F1 values (Hz) of [u] vowels in both contexts.

	u2#	ú3	u4C#	ú:5#	ú:6C#	ú7
ú1	0.0032	0.5370	0.9003	0.0680	0.0206	0.1407
u2#		0.0044	0.0266	0.0001	<0.0001	0.0003
ú3			0.9178	0.9608	0.6238	0.9875
u4C#				0.6354	0.2583	0.7812
ú:5#					0.9635	1.0
ú:6C#						0.9591

Table 3.16: F1: [u] comparisons.

As for F2, u2 and u5 are articulated significantly further back than other u's, and

there is no significant distinction between u2 and u5. Of course, u2 is unstressed and u5 is

stressed, so if F2 were an acoustic cue of stress, u2 and u5 should differ in backness.

Moreover, u2 is more back than other stressed u's, which is the opposite of what one would

expect if u2 was unstressed (and therefore centralized). Finally, the unstressed u4 does not

show any statistically significant differences compared with the stressed u1, u3, u6, and u7. Therefore, I conclude that F2 does not function as a cue for stress. It is possible that the differences observed relate to the influence of surrounding consonantal context rather than stress.

Stimuli	Both frame sentences
Cú1.Cu2	u1: 953 (226), u2: 830 (114)
Cú3.Cu4C	u3: 981 (135), u4: 1009 (86)
Cə.Cú:5	u5: 835 (83)
Cə.Cú:6C	u6: 971 (129)
Cú7.CəC	u7: 973 (106)

Table 3.17: F2 values (Hz) of [u] vowels in both contexts.

	u2#	ú3	u4C#	ú:5#	ú:6C#	ú7
ú1	<.0001	0.9932	0.8210	0.0412	0.9995	0.9990
u2#		0.0104	0.0015	1.0000	0.0276	0.0138
ú3			0.6754	0.0058	1.0000	1.0000
u4C#				0.0007	0.9734	0.9666
ú:5#					0.0187	0.0076
ú:6C#						1.0000

Table 3.18: F2: [u] comparisons.

3.4.4.2 Means of [ə]

In general, the stressed ə4 is lower than most other unstressed schwas; ə4 is significantly lower than ə1 and ə3. However, ə4 is not lower than the unstressed ə2, and it is also not significantly lower than the unstressed (but moraic) ə5. For backenss (F2), ə4 is not significantly different from the other schwas. Therefore, neither F1 nor F2 serve as clear clues of stress on schwa.

Stimuli	Both frame sentences
Cə1.Cu	ə1: 418 (172)
Cə2.CuC	ə2: 501 (170)
Cə3.Cə4C	ə3: 455 (120), ə4: 561 (72)
Cu.Cə5C	ə5: 546 (109)

Table 3.19: F1 values (Hz) of [ə] vowels in both contexts.

	ə2 (ᵊ)	ə3 (ᵊ)	ə́:4 (ᵊ)	ə5 (əᵘ)
ə1 (ᵊ)	0.5225	0.4721	0.0023	0.0242
ə2 (ᵊ)		0.9995	0.3835	0.7219
ə3 (ᵊ)			<0.0001	0.4349
ə́:4 (əᵘᵘ)				0.9856

Table 3.20: F1: [ə] comparisons.

Stimuli	Both frame sentences
Cə1.Cu	ə1: 1559 (307)
Cə2.CuC	ə2: 1670 (219)
Cə3.Cə4C	ə3: 1675 (271), ə4: 1694 (148)
Cu.Cə5C	ə5: 1568 (167)

Table 3.21: F2 values (Hz) of [ə] vowels in both contexts.

	ə2 (ᵊ)	ə3 (ᵊ)	ə́:4 (ᵊ)	ə5 (əᵘ)
ə1 (ᵊ)	0.7557	0.4761	0.3582	0.9982
ə2 (ᵊ)		0.9996	0.9959	0.9059
ə3 (ᵊ)			0.9690	0.7354
ə́:4 (əᵘᵘ)				0.6212

Table 3.22: F2: [ə] comparisons.

3.4.4.3 Standard deviations of [ə]

While the mean values of F1 and F2 do not clearly or robustly mark distinctions between the vowel types, standard deviation is revealing. Recall that there are three types of schwa: non-moraic ə1/ə2/ə3, moraic ə4, and bimoraic (and stressed) ə5. The standard deviations of F1 are different for each of these three types.

Specifically, ə4's standard deviation for F1 (72Hz) is significantly smaller than that of ə5 (109Hz) as well as ə1, ə2, and ə3 (172, 170, 120Hz resp.) at p<0.001 for all

comparisons. Also, ə5's standard deviation is significantly smaller than that of ə1, ə2, and ə3 (p<0.01 for all comparisons). ə3 exhibits a smaller standard deviation than ə1 and ə2, but the difference is marginal (p=0.041).

	ə2 (ᵊ)	ə3 (ᵊ)	ə́:4 (ᵊ)	ə5 (əᵘ)
ə1 (ᵊ)	p=0.954	p=0.041	p<0.001	p<0.001
ə2 (ᵊ)		p=0.086	p<0.001	p<0.001
ə3 (ᵊ)			p<0.001	p=0.013
ə́:4 (əᵘᵘ)				p<0.001
ə5 (əᵘ)				

Table 3.23: F-test results for schwa's F1 standard deviation.

The F2 results distinguish two of the schwa types. That is, ə4 (s.d.=219Hz) is different from ə1/ə2/ə3 (307, 219, 271Hz resp.; p<0.001), but there is no difference between ə4 and ə5 (s.d.=167Hz; p=0.212).

It is expected that schwas show more variability when they are extremely short; accordingly, there are internal variations among ə1, ə2 and ə3: ə2 has a smaller standard deviation than ə1 and ə3.

	ə2 (ᵊ)	ə3 (ᵊ)	ə́:4 (ᵊ)	ə5 (əᵘ)
ə1 (ᵊ)	p=0.004	p=0.197	p<0.001	p<0.001
ə2 (ᵊ)		p=0.067	p<0.001	p=0.019
ə3 (ᵊ)			p<0.001	p<0.001
ə́:4 (əᵘᵘ)				p=0.212
ə5 (əᵘ)				

Table 3.24: F-test results for schwa's F2 standard deviation.

The results reported above are unsurprising given the current theory. Moras are hypothesized to not only give vowels increased duration, but also more stability – i.e. their quality should be less influenced by their environment. Consequently, the bimoraic schwa

ə4 and monomoraic ə5 should vary less than the non-moraic schwas (ə1, ə2, ə3). The results accord with this expectation: moraic schwas are more stable in height and backness compared to non-moraic schwas.

It is striking that the bimoraic stressed ə4 is more stable in vowel height than the monomoraic unstressed ə5. It is likely that either bimoraicity or stress – or both – caused a reduction in height variation.

Similar F1 and F2 patterns for different kinds of schwas are also observed in American English. Flemming & Johnson (2007) found that there are significant phonetic differences between schwas in word-final position (as in *china* or *comma*) and schwas in word-internal positions (as in *suppose* or *probable*). Word-final schwas have a relatively consistent vowel quality, usually mid central, while word-internal schwa is relatively high and varies contextually in backness and lip position. Word-final schwas usually minimally contrast with higher vowels (i.e. [i] and [oʊ]), whereas word-internal schwas occur primarily in contexts where all vowel quality contrasts can be neutralized. Flemming (2009) argues that the extent of reduction is likely to be conditioned by vowel duration, observing that in Flemming & Johnson (2007)'s study, the non-final schwas averaged 64 milliseconds in duration while the word-final schwas had a mean duration of 153 milliseconds. The fact that word-final schwas had longer duration was probably due to word-final lengthening. Greater vowel duration in final unstressed schwas means less undershoot, so it is possible for word-final schwas to realize contrasts between mid central and higher vowels.

The word-final and word-internal schwas in American English are analogous to moraic and non-moraic schwas in Piuma Paiwan. That is, ə4 and ə5 have longer duration than ə1, ə2, ə3, and ə4 and ə5 have a relatively stable vowel quality. So, ə4 and ə5 have

more time to reach their articulatory targets. In contrast, ə1, ə2, and ə3 are extremely short, so there is insufficient time for the articulators to reach their target, and so more influence of the surrounding segments.

In conclusion, comparing F1 and F2 values does not differentiate stressed and unstressed vowels; vowels in different positions do not make quality distinctions. Based on the multiple vowel quality comparisons, I conclude that Piuma Paiwan does not use F1 or F2 as stress cues. However, the distinction between moraic and non-moraic schwas can be detected via their standard deviations.

3.4.5 The wug experiment

It is important to establish whether stress assignment in Piuma Paiwan is productive. If it is not, then stress could well be lexicalized, putting into question its phonological and psychological reality. The focus here is on F0, as it is the most reliable and straightforward cue of stress (see section 3.4.1).

Results from both disyllabic and trisyllabic words show that stress assignment is highly productive in Piuma Paiwan. For disyllabic words, participant S1 made six 'errors' out of 47 words in the first repetition (roughly a 13% error rate). An 'error' involved placing the F0 peak on a syllable that should not bear stress, according to the descriptions and findings above.

Almost all errors involved placing stress on schwas which are supposed to be unstressed. Only one error involved stressing an [u] which is supposed to be unstressed, in *[tutút]. In addition, the errors were found in both frame sentences. However, there were no errors in the second and third repetition for participant S1. On the other hand, participant

S2 consistently made errors on words with the form [Cu.CuC], with three errors in the second repetition (approximately a 0.06% error rate) and four errors in the third repetition (approximately a 0.09% error rate). The errors *[putút] and *[tutúp] were only found in the second frame sentence. No errors were found in the first repetition for participant S2.

For both participants, the error rates were extremely low, indicating the fact that they assigned stress correctly on disyllabic wug words in various forms. For participant S1, the error pattern can be explained by the initial novelty of some wug words. That is, the participant was unfamiliar with some of the wug words in the first repetition, but no errors were made in the second and third repetitions. For participant S2, it is possible that the form [Cu.CuC] was treated as two different morphemes, with the first one a reduplicative prefix and the second one a root. Recall that prefixes do not affect stress assignment in Piuma Paiwan (see section 3.3.1), so it is possible that participant S2 identified these words as a prefix+root combination and placed stress on the root.

Participants	S1	S2
First repetition	*[tətə́k] *[kutə́t] *[tə́tuk] *[tutə́p] *[putə́t] *[tutút]	None
Second repetition	None	*[putút] *[tutút] *[tutúp]
Third repetition	None	*[tutúk] *[tutút] *[putút] *[tutúp]

Table 3.25: Errors on disyllabic wug words.

For trisyllabic words, participants S1 and S2 produced most of the errors on words

with the form [Cu.Cu.CuC]. Participant S1 also produced three errors on words with schwa, including *[putə́tu], *[putə́tət], and *[kutə́tət]. Since participant S1 only made three errors on words with schwa in the three repetitions, the error rate is roughly 0.02% (three out of 141 stimuli). It is possible that these three words are outliers. Similarly, participant S2 produced one error on the word *[tukutú], so this error could reasonably be treated as an outlier.

Participants	S1	S2
First repetition	*[putə́tu] *[putə́tət] *[tututút] *[tuputút] *[tukutút]	*[tututút] *[tututút] *[kututút] *[pututút] *[tukutút] *[tukutú]
Second repetition	*[tututút] *[tututút]	*[tututút] *[tuputút] *[tututút]
Third repetition	*[kutə́tət] *[tututút] *[tututút]	*[tututút]

Table 3.26: Errors on trisyllabic wug words.

For errors with the form [Cu.Cu.CuC], it is possible that both participants treated these words as two morphemes, with the final syllable [CuC] as a root. The large majority of roots in the language seem to be mono- or disyllabic, so it is not surprising that a trisyllabic root was decomposed into two morphemes. Given word minima restrictions, there is only one way to decompose CuCuCuC into two roots: i.e. CuCu+CuC. So, similar to the errors for disyllabic words, participants identified the root and assigned stress to it; as a result, stress was placed on the ultimate syllable of these words, rather than the penultimate syllable.

One might expect to see errors in words with the forms [Cə.CəC] and [Cu.Cə.CəC], because stress in these two forms do not fall on the default penultimate position. However, only participant (S1) made such errors, with one in disyllabic words and two in trisyllabic words. Therefore, error rates for both types of words are low.

In summary, three generalizations emerge from the experiment on disyllabic and trisyllabic wug words. First, error rates were extremely low for each type of word. Second, few errors were found in words with schwa. Third, for words with [u], it is possible that both participants split the word into two morphemes (i.e. prefix + root), placing stress on the root. The fact that both participants successfully assigned stress to the correct syllable in most cases suggests that stress assignment in Piuma Paiwan is highly productive and signaled by F0.

3.4.6 Summary of results

To summarize the findings of the previous sections:

(21)   Summary of results

    a. Duration: is not influenced by stress.

      i. Shows that ə4, ə5, and u5 are bimoraic.

      ii. Shows that u1, u2, u3, u4, u6, u7 and ə5 are monomoraic.

      iii. Shows that ə1, ə2, and ə3 are non-moraic.

    b. Intensity

      i. Marks stress.

    c. Vowel quality (F1, F2): vowel quality variation is influenced by moraicity.

      i. Distinguishes non-moraic (ə1, ə2, ə3), monomoraic (ə4) and bimoraic (ə5).

    d. F0

      i. Marks stress for [u]: u1, u3, u5, u6, u7 are stressed; u2 and u4 are unstressed.

      ii. Marks stress for [ə]: ə1, ə2, ə3, ə5 are unstressed; ə4 is stressed.

These results accord with the present proposals. Duration was predicted to reflect moraicity, and it did: it distinguished the predicted monomoraic and bimoraic u's, and the non-moraic vs. monomoraic vs. bimoraic schwas. Similarly, vowel quality variation was predicted to vary based on moraicity and stress, and it did.

3.5 Analysis

This section provides an analysis of Piuma Paiwan's metrical system in terms of classical Optimality Theory (Prince & Smolensky 1993). The key point is that there is no need for any phonological mechanism that refers to stress (i.e. metrical heads) and schwa directly. Instead, stress's avoidance of schwa in Paiwan is entirely due to schwa's contextually-determined moraic content.

3.5.1 Moraic and non-moraic schwas

The acoustic evidence has been shown to support the claims about the phonological input and outputs repeated below:

(22)   Mappings for all the stimuli

Phonological Input	$\rightarrow$	Phonological Output	$\rightarrow$	Phonetic Form
a. $/Cu_1Cu_2/$	$\rightarrow$	$[(Cú_1{}^\mu.Cu_2{}^\mu)]$	$\rightarrow$	$[\![{}^\prime Cu_1Cu_2]\!]$
b. $/Cu_3Cu_4C/$	$\rightarrow$	$[(Cú_3{}^\mu.Cu_4{}^\mu C)]$	$\rightarrow$	$[\![{}^\prime Cu_3CuC_4]\!]$
c. $/Cə_1Cu_5/$	$\rightarrow$	$[C^{ə1}(Cú_5{}^{\mu\mu})]$	$\rightarrow$	$[\![C\breve{ə}_1{}^\prime Cu{:}_5]\!]$
d. $/Cə_2Cu_6C/$	$\rightarrow$	$[C^{ə2}(Cú_6{}^{\mu\mu}C)]$	$\rightarrow$	$[\![C\breve{ə}_2{}^\prime Cu{:}_6C]\!]$
e. $/Cə_3Cə_4C/$	$\rightarrow$	$[C^{ə3}(Cə́_4{}^{\mu\mu}C)]$	$\rightarrow$	$[\![C\breve{ə}_3{}^\prime Cə{:}_4C]\!]$
f. $/Cu_7Cə_5C/$	$\rightarrow$	$[(Cú_7{}^\mu.Cə_5{}^\mu C)]$	$\rightarrow$	$[\![{}^\prime Cu_7Cə_5C]\!]$

Specifically, when schwa lacks a mora, it is phonetically realized as extremely short, and its height and backness are highly influenced by surrounding segments, as exemplified in the first syllable in (22c), (22d), and (22e).

However, in the situation where schwa is forced to bear mora, it has a similar duration to other full monomoraic vowels, and its quality is much less influenced by its environment, as shown in the second syllable in (22f). When ə is forced to be bimoraic, it is at its longest, and least variable.

The analysis below argues that the phonological output forms involving [u], [ə], syllables, and feet in Piuma Paiwan are determined by constraints relating to ə's moraicity, prosodic headedness, and foot form. Specifically, the following constraints will be employed:

(23)   Constraints for stress assignment in Piuma Paiwan

    a. 'Moraicity' constraints

      i. *μ/ə "Incur a violation for every schwa that bears a mora."

      (From the family of constraints *μ/ə, *μ/{i,u}, *μ/{e,o}, *μ/a)

      ii. HEADEDNESSFT "Incur a violation for any Ft that does not dominate a σ."

      iii. HEADEDNESSσ "Incur a violation for any σ that does not dominate a μ."

    b. Foot form constraints

      i. FTBIN "Feet either branch at the Ft level or syllable level, but not both."

      (Adapted from Prince & Smolensky 1993/2004, McCarthy & Prince

      1993/2001).

      ii. FTBINμ "Feet must contain two moras." (after Élias-Ulloa 2006)

      iii. TROCHEE "Feet are left-headed" (i.e. ALIGN-L(Ft, σ^+))

      iv. ALLFTR "Feet are right-aligned with the PrWd" (i.e. ALIGN-R(Ft, PrWd))

    c. Faithfulness constraints

      i. IDENT-LENGTH "Incur a violation when a vowel's input length does not match

      its output length."

      ii. MAX-C "Do not delete consonants."

      iii. MAX "Do not delete segments."

3.5.2 Default footing

The default – and in fact, only – foot shape in Piuma Paiwan is the moraic trochee: a foot

consisting of two moras only (Hayes 1995). This foot is required to be aligned with the

right edge of the PrWd. The relevant foot constraints are shown below.

(24)   CVCV footing

/tsaʎíŋa/	FTBIN	TROCHEE	ALLFTR	IDENT-LENGTH
☞ a. tsa(líŋa)				
b. tsa(liŋá)		*!		
c. (tsáliᵘ)ŋaᵘ			*!	
d. tsali(ŋá:)				*!
e. tsali(ŋá)	*!			

The ranking of IDENT-LENGTH will be justified below. The foot constraints outrank all

antagonistic constraints, such as ALLFTL and IAMB (Prince & Smolensky 1993/2004).

3.5.3 Non-moraic schwa

Piuma Paiwan privileges non-moraic schwa. To do so, the ranking *μ/ə » HEADEDNESSσ

is employed, as shown in section 3.2. Below, moraless schwa is represented as [ᵊ], while

monomoraic schwa is [ə].

(25)   Moraless schwa ranking

/kəri/	*μ/ə	HEADEDNESSσ	*μ/{ə,i/u}
☞ a. kᵊ(rí:)		*	*
b. (kə́.ri)	*!		* *
c. (kᵊ.rj)		**!	

The tableau expresses the point that *μ/ə must outrank HEADEDNESSσ in order to force /ə/

to be non-moraic on the surface. Of course, other competitors raise questions about how

*μ/ə is ranked with respect to the foot constraints.

3.5.4 Inducing bimoraicity on full vowels

Words that are underlyingly /CəCV/ surface as [Cᵊ(CV́ᵘᵘ)] (i.e. phonetically ⟦Cə̆ˈCV:⟧).

The /V/ is lengthened because the foot constraints require a bimoraic foot. Furthermore, the ranking of *μ/ə means that it is more costly to have a moraic [ə] than to lengthen the full vowel, as shown below.

(26)   Bimoraic full vowel ranking

/kəri/	FTBINμ	*μ/ə	HDσ	ID-LENGTH
a. (ká.ri)		*!		
☞ b. kᵊ(rí:)			*	*
c. (kᵊ.rí)	*!			

In the tableau above, candidate (26a) has a perfect bimoraic right-aligned trochaic foot. However, it fatally violates *μ/ə. Candidate (26b) also has a bimoraic right-aligned trochee while avoiding a moraic schwa. It achieves this by lengthening the final vowel, thereby making it bimoraic. Crucially, *μ/ə outranks IDENT-LENGTH, with the effect that it is better to lengthen a vowel than have a moraic schwa.

Candidate (26c) shows that it is impossible to both have a non-moraic schwa and not lengthen – such a structure fatally violates FTBINμ as the candidate contains a non-moraic schwa and a monomoraic full vowel, meaning that the foot has only one mora.

3.5.5 Monomoraic schwa

While output [ə] is usually non-moraic due to *μ/ə outranking HEADEDNESSσ, in one situation it is monomoraic: /CVCəC/ → [(CV́ᵘ.CəᵘC)]. Non-moraic schwa is not possible here because of foot form: feet must be bimoraic and right-aligned. The tableau below

shows that other candidates fail for foot-based reasons, or unnecessary violation of IDENT-

LENGTH.

(27)   Monomoraic schwa ranking

/tidəq/	FTBIN	ALLFTR	FTBINμ	*μ/ə	HD-σ	ID-LENGTH
☞ a. (tí.dəq)				*		
b. ti(də́:q)				*		*!
c. (tí:.dᵊq)	*!				*	*
d. (tí.dᵊq)			*!		*	
e. (tí:)dᵊq		*!				

Candidate (27a) violates *μ/ə once, but does not violate any foot-based constraint, or

IDENT-LENGTH. In contrast, candidate (27b) violates both *μ/ə and IDENT-LENGTH, and

the other candidates violate foot-form constraints.

Importantly, the constraint FTBIN is violated when a foot branches at *both* the foot

and syllable level, as in candidate (27c)'s [(tí:dᵊq)]. In other words, FTBIN is violated by

(Hm) feet, where *m* is a minor syllable.

3.5.6 Bimoraic schwa

The remaining form to explain is /CəCəC/ → [Cᵊ(Cə́ᵘᵘC)]. The existing ranking already

accounts for this form: with *μ/ə outranking IDENT-LENGTH, it is better to minimize

moraic schwas than preserve underlying length.

(28)   Bimoraic schwa ranking

/ləʎət/	FTBINμ	*μ/ə	HD-σ	ID-LENGTH
☞ a. lᵊ(ʎə́:t)		*	*	*
b. (lə́.ʎət)		**!		
c. (lᵊ.ʎᵊt)	*!			

Importantly, *μ/ə is violated for every schwa that bears some mora, rather than incurring one violation per mora on schwa. So, candidate (28a) incurs one violation of *μ/ə because there is one schwa that bears moras, while candidate (28b) violates the constraint twice because two different schwas bear a mora.

Some generalizations arise from the analysis. Firstly, there is no need to have foot constraints that explicitly mention minor syllables. FTBIN is defined as "*Either* branch at the foot or syllable level, <u>but not both</u>." As a result, feet like (Hm) and (mH) are banned because they branch at both the foot and syllable level. Other feet with minor syllables – i.e. (Lm) and (mL) – are banned because of FTBINμ. In contrast, (LL) and (H) satisfy both FTBIN and FTBINμ.

While it may seem that HEADEDNESSFT would be useful in Piuma Paiwan, it does not do any work that the footing constraints don't already do. That does not mean that HEADEDNESSFT has no use; we will see its effect in other systems.

In contrast, HEADEDNESSPRWD *is* necessary to make sure that every PrWd has a foot, otherwise unfooted [CᵊCᵊ] would win, as it probably does in Chuvash (Dobrovolsky 1999). Dobrovolsky measured peak intensity, average intensity, duration, fundamental frequency, and the intensity integral of disyllabic words with the following combinations: CVCV, CVCə, CəCV, and CəCə. The results show that the first ə in CəCə is not realized by greater peak, average, and total intensity, nor by increased duration. Instead, the first Cə has the highest fundamental frequency, which subsequently falls throughout the rest of the word. This initial peak in fundamental frequency is a consistent property of the initial syllable, even when it was not predicted to be stressed. Dobrovolsky concludes that CəCə words are actually unstressed. In current terms, Chuvash CəCə words lack any PrWd or

foot head. As a consequence, HEADEDNESSPRWD is violated in Chuvash (i.e. *μ/ə »

HEADEDNESSPRWD, HEADEDNESSFT, HEADEDNESSσ).

3.5.7 The ban on absolute word-final schwa

In Piuma Paiwan, absolute word-final schwa is banned. There are no alternations to show

what happens to an input such as /CVCVCə/. Here, I will assume that word-final schwa

deletes: i.e. the output is [CVCVC].

Such a response to word-final schwa is explained by the current constraints and

their ranking. If word-final schwa is not deleted in such a situation, it will be parsed into a

foot due to ALLFTR. Of course, if a schwa bears any moras, it fatally violates *μ/ə, as

shown in the tableau below, candidates (29a) and (29d). However, if the schwa surfaces as

non-moraic in the output, it violates either FTBIN or FTBINμ, depending on the number of

moras on the preceding [V], as illustrated in (29b) and (29c). So, deleting word-final schwa

(in candidate (29e)) violates the lower ranked constraint MAX-V, but satisfies the foot form

constraints and *μ/ə.

(29)   /CVCVCə/ as input

/CVCVCə/	FTBIN	FTBINμ	*μ/ə	MAX-V	HD-σ	ID-LENGTH
a. CVᵘ(CV́ᵘ.Cəᵘ)			*!			
b. CVᵘ(CV́ᵘᵘ.Cə)	*!				*	*
c. CVᵘ(CV́ᵘ.Cə)		*!			*	
d. CVᵘ.CVᵘ(Cə́ᵘᵘ)			*!			*
☞ e. (CVᵘ.CV́ᵘC)				*		

When the input is /CVCVCəC/, it surfaces as [CVᵘ(CV́ᵘ.CəᵘC)], with the schwa surviving

in the output. The reason for keeping the schwa in the closed syllable is straightforward:

Piuma Paiwan forbids complex onsets and codas (Yeh 2011: 10), so deleting the schwa in a closed syllable would create a consonant cluster in the coda position. Candidate (30e) thus violates *COMPLEX (Prince & Smolensky 1993/2004). Candidate (30f) is eliminated because it incurs a violation of MAX-C.

(30)   /CVCVCəC/ as input

/CVCVCəC/	*COMPLEX	MAX-C	FTBIN	FTBINμ	*ə/μ	MAX-V	ID-LENGTH
☞ a. CVμ(CV́μ.CəμC)					*		
b. CVμ(CV́μμ.CᵊC)			*!				*
c. CVμ(CV́μ.CᵊC)				*!			
d. CVμ.CVμ(Cə́μμC)					*		*!
e. (CV́μ.CVμCC)	*!					*	
f. (CV́μ.CVμC)		*!				*	

3.5.8 Ranking summary

The resulting ranking summary for Piuma Paiwan is shown in (31). The interaction between schwas' ability to bear a mora and foot form constraints is clearly reflected in the ranking hierarchy. That is, the foot in Piuma Paiwan strictly branches at either the foot or syllable level (but never both). There is a strong preference for schwa to be non-moraic. However, if a schwa is required to be parsed into a foot, foot form constraints will force the schwa to be either mono-moraic or bimoraic, depending on the types of vowels in the foot.

(31)   Ranking summary for Piuma Paiwan

*COMPLEX   MAX-C   FTBIN FTBINμ TROCHEE   ALLFTR   HEADEDNESSPRWD

*μ/ə

MAX-V   HEADEDNESSσ   IDENT-LEGNTH

*μ/ə,i/u   *μ/ə,i/u,e/o
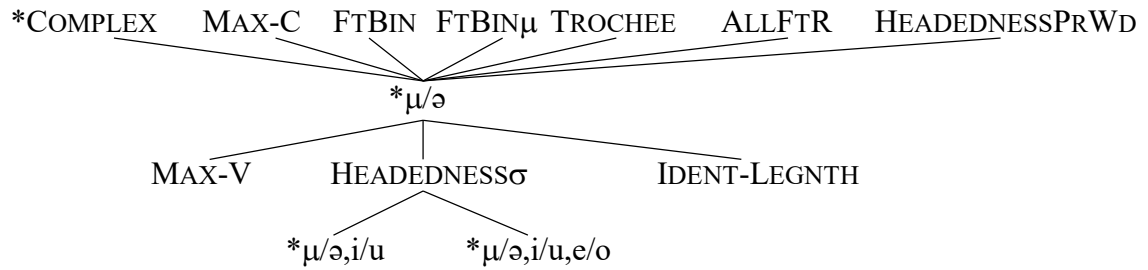
3.5.9 Alternative analyses

3.5.9.1 de Lacy (2002, 2004, 2006)

de Lacy (2002, 2004, 2006) (hereafter deL) proposes a theory that involves constraints that

directly relate sonority to foot heads, and in fact to all prosodic levels. In the deL theory,

the sonority hierarchy can be expressed in the form of constraints in Optimality Theory.

The constraint forms and definitions are given schematically in (32). The category foot

head (HD) refers to the root node of the head mora of the head syllable of a foot while the

category foot non-head (NON-HD) refers to all root nodes that are not the head of a foot.

(32)   Sonority constraints *(NON-)HD$_\alpha$/β

    a. *HD$_\alpha$≤β

    Assign a violation for every segment in Hd$_\alpha$ that is lower than or equal to β on

    scale F.

    b. *NON-HD$_\alpha$≥β

    Assign a violation for every segment in non-Hd$_\alpha$ that is greater than or equal to β

    on scale F.

The constraints *HD$_\alpha \leq \beta$ and *NON-HD$_\alpha \geq \beta$ have the ability to restrict certain vowels of different sonority in head and non-head positions. The constraint *HD$_\alpha \leq \beta$ plays an essential role in sonority-driven systems since it can ban vowels with low sonority in head position. In particular, *HDFt$\leq\{\vartheta\}$ would play a crucial role in Piuma Paiwan stress since it is the foot head which bans low sonority vowels, as in (33). Some constraints and their rankings are omitted in the tableau below: FT-BIN dominates ALL-FT-R, and TROCHEE is undominated.

(33)   *HDFt$\leq\{\vartheta\}$ » FT-BIN

/səqu/	*HDFt$\leq\{\vartheta\}$	FTBIN
☞a. sə(qú)		*
b. (sə́qu)	*!	

The key is that the non-metrical constraint *HDFt$\leq\{\vartheta\}$ must outrank the metrical constraint FTBIN in order for candidate (33a) to be optimal. Candidate (33b) is ruled out because the head contains a schwa. The competitor [(səqú)], with an iambic foot, is eliminated through the undominated constraint TROCHEE. The metrical structure is changed due to the fact that *HDFt$\leq\{\vartheta\}$ outranks FT-BIN.

However, there are two challenges for the deL analysis.

One problem is that *HDFt$\leq\{\vartheta\}$ fails to capture the stress pattern in [Cə.CəC] words, as shown in (34) below. When a disyllabic word contains two schwas, the foot head is the ultimate syllable. However, the constraint *HDFt$\leq\{\vartheta\}$ penalizes both candidates (34a) and (34b) equally because the head contains a schwa. In other words, *HDFt$\leq\{\vartheta\}$ is not decisive when a head has to have a schwa. Crucially, the actual winner (34a) fatally violates the lower-ranked constraints FTBIN because it has a unary foot. Given the constraint ranking,

candidate (34b) is falsely predicted to be the optimal output.

(34)   Wrong output

/tsəkəs/	*HDFt≤{ə}	Ft-Bin
a. tsə(kə́s)	*	*!
☞*b. (tsə́kəs)	*	

In other words, the deL theory is unable to straightforwardly account for the 'default-to-opposite' character of stress assignment in Piuma Paiwan. This result illuminates the workings of the current theory. The present theory proposes that moraic structure in [CəCu] and [CəCəC] is in fact *identical*: the final syllable is moraic in both forms, and the penult is non-moraic. Consequently, the fact that feet form in exactly the same way in the two forms follows straightforwardly from the moraic and syllabic structure.

The second challenge for the deL theory is the difference in moraic quantity found in the various forms. In the deL theory, stress avoids [ə] because of its sonority, not because of its lack of moraicity. Finally, de Lacy (2004: 31-33) rejects a representational theory in which schwa has a different representation than other vowels. The problem is then how to explain the difference in duration, intensity, and quality found between ə1/ə2/ə3 vs. ə4 vs. ə5. The present theory explains this as a difference in no moras vs. one mora vs. two moras (and stressed). deL's theory cannot distinguish the [ə]s (at least ə1/2/3 vs. ə4) on moraic content alone, so their difference is unexplained.

In other words, the present theory and deL's are profoundly different in how they achieve their ends. In the current theory, the key is moraicity: schwa is forced to have a mora when it is a foot head, and when foot form calls for it. Foot form is a side-effect of moraicity. In the deL theory, foot form is directly determined by sonority.

The final point is that Piuma Paiwan has no *need* of a direct sonority-foot constraint. Allowing the existence of non-moraic schwa, there is no need to appeal to heads avoiding schwa.

3.5.9.2 Yeh (2011)

In an approach reminiscent of deL's, Yeh (2011) proposes a constraint *Ft/ə to account for stress assignment in [Cə.CəC] words. The constraint *Ft/ə is violated for each schwa in a foot. Yeh (2011) argues that by ranking this constraint over FT-BIN, we could eliminate the candidate with two schwas in a foot, as shown in (35). In other words, parsing a degenerate foot is preferable to a binary foot containing two schwas. Candidate (35b) is ruled out because it contains two schwas in a foot, whereas candidate (35a) contains only one schwa in a unary foot.

(35) *Ft/ə » FT-BIN

/tsəkəs/	*Ft/ə	*HDFt≤{ə}	FT-BIN
☞a. tsə(kə́s)	*	*	*
b. (tsə́kəs)	**!	*	

Yeh (2011) further states that the intuition behind this analysis is that schwa is an undesirable member of a foot, whether or not it occupies the peak position. Therefore, Piuma Paiwan exiles it from the metrical structure, preferring to parse a non-binary, degenerate foot instead.

Like the deL theory, Yeh (2011)'s theory proposes that there is a constraint that directly relates sonority to foot structure.

There are a few general problems with Yeh (2011)'s proposal. One is that it still

relies on the deL direct sonority-foot constraints. Another is that it has unattested typological predictions. One is that it can be used to do 'reverse' vowel neutralization in unstressed syllables. *Ft/ə bans schwa even in the non-head position of a foot. So, with *Ft/ə outranking appropriate faithfulness constraints, /ə/ would become *more sonorous* when it appears in the nonhead syllable of a foot: e.g. /pəki/ → [(pe.kí)]. This prediction is the opposite of the kinds of vowel reduction systems reported in Crosswhite (2001) and de Lacy (2006: ch.7).

3.5.9.3 Rasin (2017)

Raisin (2017) (hereafter 'R') argues that stress systems that avoid schwa, like Piuma Paiwan's, are due to a representational defect of schwa: i.e. schwa can be featurally empty (on a language-specific basis). In addition, there is a phonological process that avoids stress (specifically, grid marks) on featureless vowels.

In contrast, the current theory has three kinds of schwas: non-moraic, mono-moraic, and bimoraic. Stress processes cannot 'see' features – they instead access the moraic level in the formation of syllable and foot structure.

In R, a stress system very similar to Piuma Paiwan's – Mari – is analyzed. R involves stressing the rightmost vowel with features, else the leftmost featureless vowel. In Piuma Paiwan, stress would fall on the penultimate vowel with features, otherwise the rightmost featureless vowel.

The problem for such an analysis is explaining why the 'stressed' [ə] is so acoustically different from the unstressed schwas in Paiwan. If the final [ə] in [CəCəC] is featureless, then it is a mystery why it has greater duration and less F1 variation than the

other schwas.

In short, R's theory relies on schwa being featurally empty in all environments. In contrast, the present theory has argued that there are *three* kinds of schwa in Piuma Paiwan, and their appearance is conditioned by foot structure. This present theory has the added benefit of providing a clear and comprehensive account of all the acoustic properties of the various schwas.

3.6 Implications

The majority of sonority-driven stress cases involve stress avoiding schwa (or central vowels). However, this study shows that this type of sonority-driven stress should be analyzed as stress avoiding moraless schwa rather than avoiding its low sonority. A similar observation has been made by Hargus (2001), who argues that quality-sensitive stress, at least the central vs. peripheral type, can be considered a special case of quantity-sensitive stress, and requires no metrical peak-specific formalization. Drawing on evidence from Sahaptin and Witsuwit'en, Hargus (2001) argues that the avoidance of stress stems from the phonetic shortness of central vowels. Although Hargus (2001)'s analysis does not touch on the moraic representation of central vowels, the phonetic patterns observed in the two languages can be explained by the theory proposed here.

Chapter 4 (also see Shih 2016, 2018) will present experimental evidence against previous claims that [a] attracts stress away from the default stress position in Gujarati (de Lacy 2006). Of the five types of phonetic evidence examined, only F1 provides clear evidence for stress. It reveals stress to be consistently penultimate, not sonority-driven. Gujarati is important for sonority-driven stress because it is one of very few reported cases where stress treats certain peripheral vowels differently from other peripheral vowels.

Therefore, it casts doubt on the existence of sonority-driven stress, especially for the type with peripheral vowel distinctions.

One theoretical issue raised here is the problem for analytical frameworks such as Optimality Theory because of the property of symmetric effect (see chapter 2). In constraint-based theories, 'problems' and 'solutions' are decoupled. For example, in the original analysis of Gujarati, the problem was "stressed low sonority vowels", and this problem was solved by moving stress to higher sonority vowels. However, the same problem could be solved in many other ways: e.g. by changing the vowels to higher-sonority ones. This issue will be addressed in depth in chapter 4.

3.7 Conclusion

This chapter has shown that there is no evidence for sonority-driven stress in Piuma Paiwan. Specifically, I have argued that schwas are moraless, and their apparent stress repulsion is a side-effect of requirements on foot form. Importantly, Piuma Paiwan shows that there are three kinds of schwa: bimoraic, monomoraic, and non-moraic. The types are detectable through their different durations and vowel quality variations. Stress, on the other hand, is signaled by F0 and intensity.

This finding is important because Piuma Paiwan belongs to the central vs. peripheral type in the typology of sonority-driven stress. If all such stress systems are amenable to the kind of analysis presented here, then there is no sonority-driven stress – i.e. there are no constraints that directly relate sonority to metrical structure. One difficult challenge of this conclusion involves the asymmetry between metrical structure and vowel sonority: if vowel sonority cannot affect metrical structure, then why does metrical structure affect vowel sonority? This issue will be addressed in chapter 4.

CHAPTER 4

ILLUSORY SONORITY-DRIVEN STRESS IN GUJARATI

4.1 Introduction

This chapter provides new evidence against previous descriptions that stress assignment in Gujarati is sonority-driven (Cardona 1965, Adenwala 1965, Mistry 1997, de Lacy 2002, 2006, Cardona & Suthar 2003, Doctor 2004, Schiering & van der Hulst 2010, Campbell & King 2011, Modi 2013). I will show that stress in Gujarati is not sensitive to vowel sonority, based on acoustic evidence. Specifically, I will argue that the highly sonorous vowel [a] does not attract stress away from the default position – stress always falls on the penultimate syllable. There are several theoretical and methodological implications for this finding (see section 4.5 for discussion). Most importantly, it casts doubt on the existence of sonority-driven stress because Gujarati is the most extensively described case for its existence (de Lacy 2002, 2006, 2007).

A 'sonority-driven' stress system is one where the relative sonority of syllabic nuclei is a factor in determining the position of metrical structure. The universal sonority hierarchy is given in (1) (Kenstowicz 1997, de Lacy 2002, 2004, 2007).

(1)   Universal sonority hierarchy (Kenstowicz 1997: 162, de Lacy 2002: 55)

low peripheral > mid peripheral > high peripheral > mid central > high central

'a'　　　　　**'e, o'**　　　　　**'i, u'**　　　　**'ə'**　　　　**'ɨ'**

Peripheral vowels are more sonorous than central ones, and within those groups lower vowels are more sonorous than higher ones.

Of all known sonority-driven stress systems, Gujarati is probably the most well described case with distinctions among peripheral vowels (de Lacy 2004: 193; see section 4.2.2 for details). Although the descriptions disagree in several ways, almost all agree that stress seeks out the most sonorous vowel [a], disregarding the default penultimate position (see section 4.2.2). Examples are given in (2).

(2)   Gujarati with sonority-driven stress (data from de Lacy 2002: 72)

a. Default stress on penult

[sáɖa]   'plus ½'

[dʒája]   'let's go'

b. Stress falls on ultimate [a] if penult is a non-[a] vowel

[ʃikáɾ]   'a hunt'

[hɛɾán]   'distressed'

c. Stress falls on penultimate [a] if ultima is a non-[a] vowel

[sáme]   'in front'

[sáɖu]   'plain'

In (2a), stress falls on the penultimate syllable – the default position – when both vowels are [a]. However, stress is retracted to an [a] in the final syllable when the penult contains other vowels – all of which are less sonorous than [a], as in (2b). If the ultima contains a vowel other than [a], stress falls on the penultimate position, as in (2c). In other words,

since [a] is more sonorous than other vowels, it attracts stress away from the default position, so it is a case of 'sonority-driven stress'.

The goal of this chapter is to determine whether Gujarati's [a] does in fact attract stress. I focus on the acoustic realization of stress. Cross-linguistic studies have shown that multiple acoustic measures may correlate with stress in vowels. Typically, stressed vowels may have a higher pitch (e.g. Lieberman 1960, Gordon 2004, Gordon & Applebaum 2010), greater intensity (e.g. Fry 1955, Lieberman 1960, Everett 1998, Gordon 2004, Gordon & Applebaum 2010, Gordon & Nafi 2012), or longer duration (e.g. Fry 1955, Lieberman 1960, Everett 1998, Gordon 2004, Gordon & Applebaum 2010). Differences in F1 and F2, associated with differences in vowel quality, have also been found (e.g. Gordon 2004, Garellek & White 2015). This study is, with Bowers (under review), among the few to offer an extensive acoustic analysis of a putative case of sonority-driven stress (also see Lehiste *et al*. 2005).

I performed an experiment to determine whether stress always falls on [a]. Four male and two female native Gujarati speakers participated in the experiment. Disyllabic words with the shape [Ca.Ca], [Ca.Cψ], and [Cψ.Ca] (where ψ ranges over [o, u, i]) were used to allow multiple comparisons of [a] in both putatively stressed and unstressed states. Vowels other than [a] (i.e. [o, u, i]) in different positions were also examined in order to provide further evidence. Acoustic correlates of stressed/unstressed vowels were measured, including intensity, duration, F0, F1 and F2.

The finding is that the acoustic facts are consistent with Gujarati having consistent penultimate stress, rather than attraction of stress to [a]. Of the five types of phonetic evidence examined, F1 provides clear evidence for consistent penultimate stress.

Specifically, vowels in the penult are more peripheralized than vowels in the final syllable. Stress position is not clearly signaled by duration, F0, intensity, or F2. In particular, duration is confounded with phrase-final lengthening and F0 a LH intonation contour. Results from comparing non-[a] vowels in different positions also support the claim that Gujarati has consistent penultimate stress.

The significance of this result potentially goes beyond Gujarati. Since Gujarati is the most well described case of sonority-driven stress, it raises the possibility that all sonority-driven stress cases, or at least those involving peripheral vowel distinctions, have been misreported. Motivations for potential misinterpretation of such systems are discussed in section 4.5.2.

This chapter is organized in the following manner: section 4.2 presents the differences between metrical and non-metrical structure. Section 4.3 is the methodology. Section 4.4 illustrates the acoustic evidence against sonority-driven stress in Gujarati, focusing on [a]'s stress-attracting properties. Section 4.5 discusses the theoretical and perceptual implications. Section 4.6 concludes this chapter.

4.2 Background

This section situates the present study in phonological theories of sonority-driven metrical structure and in theories of the acoustic manifestation of metrical heads. Section 4.2.1 discusses phonological theories of sonority-driven stress and how the various descriptions of Gujarati stress are expressed in them. Section 4.2.2 discusses the disagreement among previous descriptions of Gujarati stress assignment. Section 4.2.3 identifies potential phonological evidence for metrical structure apart from phonetic realization. Finally,

section 4.2.4 discusses theories of the phonetic realization of metrical structure, how they relate to extant impressionistic descriptions, and how they relate to the rest of this study.

Gujarati is a Western Indo-Aryan language and is the official language of the state of Gujarat. It is also spoken in Maharashtra and Rajasthan states, and by Gujarati communities in every major city in India. In addition, significant communities of Gujarati speakers live in the United Kingdom, East Africa and the United States. The total number of speakers is at least 45 million (Campbell & King 2011).

4.2.1 The phonology of sonority-driven stress

The theories developed in Kenstowicz (1997) and de Lacy (2002, 2004, 2006) allow the location of metrical structure to be influenced by segmental sonority (also see McGarrity 2003, Crowhurst & Michael 2005).

The universally invariant part of the theory relates to the sonority scale: it is fixed as in (3).

(3)   Vocalic portion of the sonority hierarchy (de Lacy 2006: 68)

⟨ low vowels ⟩ mid peripheral vowels ⟩ high peripheral vowels ⟩ mid central vowels

⟩ high central vowels |

Metrical heads prefer higher sonority segments, and non-heads prefer lower sonority segments.[1] For example, the constraint *HD$_{Ft}$/ɨ bans the least sonorous vowels in head

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[1] A complicating factor is that a metrical head at one prosodic level can be a non-head at another prosodic level. In de Lacy (2004: 63-66), an element can be the Designated Terminal Element (DTE) of lower prosodic levels, such as mora, syllable, and foot, but it is a non-DTE at higher levels, such as prosodic word,

positions, while the *NON-HD_Ft/a prohibits the most sonorous vowels in non-head positions (de Lacy 2004, 2007).

In de Lacy (2004)'s theory, contiguous portions of the scale can be collapsed ('conflated') into single categories – a point that is crucial for the analysis of Gujarati, and illustrated below. In all theories, the sonority-metrical constraints interact with standard metrical constraints on foot form and edge-alignment – sonority-sensitivity is not an alternative to edge-alignment; it is an additional factor.

Some background on Gujarati segments, syllable, and word structure is necessary to understand stress assignment. Gujarati has ten surface vowels (eight of which are phonemic). The open-mid vowels /ɛ/ and /ɔ/ have a restricted distribution and low frequency of occurrence (Mistry 1997: 660). Allophonic variation [í ú]~[ɪ ʊ] conditioned by stress is discussed in section 4.2.3.

(4)   Gujarati vowel inventory

Front	Central	Back
i		u
ɪ		ʊ
e	ə	o
(ɛ)		(ɔ)
	a	

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phonological phrase, and so on. Here, the relevant prosodic level is the Foot/PrWd (Foot heads in the stimuli are also PrWd heads), and the frame sentences used also hold higher prosodic levels constant.

(5)   Gujarati consonant inventory

	labial		dental		alveolar		(alveo-)palatal		retroflex		velar		glottal
-vd Stops	p	pʰ	t	tʰ			tʃ	tʃʰ	ʈ	ʈʰ	k	kʰ	
+vd Stops	b	bʰ	d	dʰ			dʒ	dʒʰ	ɖ	ɖʰ	g	gʰ	
fricatives					s	z	ʃ						h
nasals	m				n		(ɲ)		ɳ		(ŋ)		
laterals					l				ɭ				
flap					ɾ								
glides	ʋ~w						j						

The Gujarati consonant inventory is given in (5). In particular, stops are crucial in this study as they are onsets of the stimuli (see section 4.3.2). The syllable structure of the language is $(C_1)(C_2)V((C_3)C_4)$ (de Lacy 2002: 71). Onsets and codas are optional, as shown by [e.ɖi] 'heel'. Gujarati allows consonant clusters, mostly in initial and medial position; only a restricted set of consonant clusters can occur at the end of a word. Geminate consonants can appear in medial position, as shown by [sətta] 'power' and [sikko] 'coin'.

Morphologically, Gujarati is an agglutinative language; grammatical information is encoded by way of affixation (largely suffixation). Morpheme boundaries will be marked where relevant, though no description reports that stress is influenced by morpheme boundaries.

There are several descriptions of stress assignment in Gujarati. The descriptions are entirely impressionistic – they are reports of the authors' intuitions about syllable prominence. There is little discussion of phonological evidence (see section 4.2.3).

While there are non-trivial differences between the descriptions, three themes emerge: (a) the default position for stress is the penult, (b) stress is attracted to [a], and (c) stress avoids [ə]. The descriptions focus almost exclusively on disyllabic and trisyllabic

words; longer roots are rarer, and perhaps non-existent, and inflectional affixes seem to have no effect on stress placement. The only description of affixes is by Modi (2013: 160): the causative suffix *-av* takes the stress and reduces the length/stress of the previous syllables irrespective of which vowel proceeds it, e.g. [múk] → [mukáv] 'keep!'.

Focusing on [a], the descriptions generally agree that stress can be attracted to [a] away from the penultimate position. For example, stress falls on the default penultimate position in [sáɖa] 'plus ½', but stress is attracted to final [a] in [ʃikáɾ] 'a hunt' (de Lacy 2002: 72). In terms of the sonority-driven stress theories, such sonority-attraction can be modeled in the following way. The departure of the stress from the default position indicates that *HD$_{Ft}$≤{e,o} has an overriding influence on the relevant metrical constraints. I use a disyllabic word [hɛɾán] 'distressed' to illustrate this point in (6). The constraint *HD$_{Ft}$≤{e,o} is violated when the head of a foot (i.e. the stressed syllable) contains a segment with lower sonority than [a]. The constraints TROCHEE and FT-BIN are well known from the literature on metrical stress, and require feet to be left-headed and binary respectively (Prince & Smolensky 2002).

(6)   Stress on the ultimate [a] (de Lacy 2002: 75)

/hɛɾan/	*HD$_{Ft}$≤{e,o}	TROCHEE	FT-BIN
☞a. hɛ(ɾán)			*
b. (héɾan)	*!		
c. (hɛɾán)		*!	

The key point is that the sonority constraint *HD$_{Ft}$≤{e,o} must outrank the metrical constraint FT-BIN in order for candidate (6a) to be optimal. Candidate (6b) is ruled out because the head contains an [ɛ] which is less sonorous than [a]. Although candidate (6c) satisfies the head sonority requirement, it fatally violates the foot form constraint TROCHEE.

4.2.2 Disagreement

At this point, it is important to acknowledge the nature and extent of the disagreement between previous descriptions. The descriptions' reports about sonority are summarized in (7). If vowels are grouped inside the same rectangle, the description treats them as a class in stress assignment. For example, in Mistry (1997)'s description, stress is attracted to [a] if it is present, but otherwise falls on a default position regardless of vowel quality. Several descriptions also present quite different principles for stress assignment in disyllables vs. trisyllables, and claim that syllable shape affects stress, and that there is free variation; these will be discussed below where relevant.

• *Fixed stress only*

In some descriptions, the position of stress is fixed. For example, Turner (1921) claims that stress generally falls on the penultimate syllable, without mentioning any differences in two versus three syllable words. Similarly, Master (1925) reports that stress always falls on the penult in disyllables, even when words historically had final stress. Patel & Mody (1960) report that stress always falls on the initial syllable in both disyllables and trisyllables.

When vowel sonority is not a factor, stress is reported to fall on the penult in disyllabic words (Cardona 1965, de Lacy 2002, Mistry 1997, Cardona & Suthar 2003, Doctor 2004, Schiering & van der Hulst 2010). There is disagreement, however, about stress position in trisyllabic words. Master (1925) and Mistry (1997) report that stress is on the initial syllable, while de Lacy (2002) claims that the penult has stress, as does Cardona

(1965), Cardona & Suthar (2003), Doctor (2004), and Schiering & van der Hulst (2010).[2] The present study focuses entirely on disyllabic words.

Regardless of differing reports, the central point on which almost all descriptions agree is that Gujarati stress falls on the penultimate syllable in the default situation in disyllables. The only dissent is from Adenwala (1965), who reports that stress falls on the ultimate syllable when a disyllabic word contains [i] or [u] in the penult and ultima (e.g. [Ci.Cí], [Ci.Cú], [Cu.Cú], [Cu.Cí]).

• *Vowel quality: [a]*

Most descriptions agree that stress is affected by vowel quality. However, as (7) shows, there are significant variations between descriptions. The table shows how different vowels are grouped for stress assignment purposes by the various descriptions. For example, Turner (1921) treats all vowels as the same – vowel quality is ignored in stress assignment. In contrast, Cardona (1965) describes stress as treating [a], [ɛ ɔ e o u], [i], and [ə] as four distinct categories in trisyllables: stress is attracted first to [a], then to vowels other than [i], and finally to [ə] if there is no other option. Even so, most descriptions agree that [a] can attract stress away from the penultimate position to either the antepenult or final syllable if the penult is not [a].

In contrast, Adenwala (1965) reports that stress is attracted to all non-high peripheral vowels (not just [a]), and Campbell & King (2011) and Modi (2013) do not

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[2] It is possible that Master (1925) and Mistry (1997) listened to words in isolation or in higher prosodic domain-initial positions. In such environments, the initial syllable is likely to be more perceptually prominent than the penultimate syllable (e.g. Fougeron & Keating 1997, Cho & Keating 2001, Keating et al. 2003, Cho & Keating 2009, Georgeton & Fougeron 2014). The goal of this study is to verify whether stress assignment in Gujarati is sonority-driven or not, and to that end focuses on disyllabic words; additional experiments will be required to verify the actual location of stress in trisyllabic words.

recognize any stress influences among peripheral vowels.

(7) Descriptions of Gujarati stress

Source	Categories
Penultimate stress	
Turner 1921 Master 1925: 2σ	[a ɛ ɔ e o u i ə]
Sonority-driven stress	
Mistry 1997 de Lacy 2002: 2σ Cardona & Suthar 2003: 2σ & 3σ	[a] [ɛ ɔ e o u i ə]
Cardona 1965: 2σ de Lacy 2002: 3σ Doctor 2004: 2σ Schiering & van der Hulst 2010: 2σ & 3σ	[a] [ɛ ɔ e o u i] [ə]
Cardona 1965: 3σ Doctor 2004: 3σ	[a] [ɛ ɔ e o u] [i] [ə]
Adenwala 1965: 2σ	[a ɛ ɔ e o] [u i] [ə]
Campbell & King 2011 Modi 2013: 2σ	[a ɛ ɔ e o u i] [ə]

• *Vowel quality: schwa*

Many descriptions also report avoidance of stressed schwa, though such avoidance can be limited. For example, Cardona (1965) and de Lacy (2002) report avoidance of stressing penultimate schwa only if there is a non-schwa in the antepenult. Some descriptions make further quality distinctions (e.g. Cardona 1965 and Doctor 2004 for trisyllables, though de Lacy (2006: 234) claims that the relevant vowels are deleted). Campbell & King (2011) asserts that a very light stress is usually placed on the first syllable, sometimes elsewhere depending on the presence and position of /ə/.

• *Vowel quality: other vowels*

There is no consensus regarding the status of mid vowels [ɛ ɔ e o] and high vowels [i u]. Cardona (1965)'s and Doctor (2004)'s descriptions cannot be adequately modeled in

Kenstowicz (1997)'s and de Lacy (2002, 2004, 2006)'s theories because they distinguish [i] from [u], though de Lacy (2006: 241-242) suggests that [i] is deleted in the majority of these environments.

Below I discuss the disagreements on three aspects of the metrical system of Gujarati: syllable numbers (disyllables and trisyllables), syllable shapes (open and closed syllables), and free variation.

• *Disyllabic vs. trisyllabic words*

There are different proposals for sonority preference with respect to disyllables and trisyllables.[3]

For disyllabic words, de Lacy (2002), Cardona (1965) and Doctor (2004) agree that [a] attracts stress away from the default position, but Cardona (1965) and Doctor (2004) report that when [ə] appears in either the penult or ultima, stress is repelled to the non-[ə] syllable.

On the other hand, Adenwala (1965) proposes a more complicated hierarchy: the mid vowels conflate with [a] as a group. That is, stress is attracted by both low and mid vowels rather than the low vowel alone. Stress avoids [i] and [u] when the non-[i u] syllable contains one of the low or mid vowels. However, stress seeks [i] and [u] when [ə] appears in the non-[i u] syllable. It is important to mention that Adenwala's proposal applies to words with the shape CV.CVC. For words with the shape CV.CV and CVC.CVC, stress always falls on the first syllable.

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[3] It is difficult to explain why descriptions disagree about sonority variation in disyllabic and trisyllabic words. For general discussion, see section 4.5.2 on the perceptual implications of the present findings.

Finally, Campbell & King (2011) and Modi (2013) report that stress avoids [ə] only.

All of the descriptions can be modeled in the theories cited, but of course by different means. de Lacy (2002)'s, Cardona (1965)'s, and Doctor (2004)'s descriptions can be modeled in the theories by using the constraint *HD$_{Ft}$≤{e,o}. Adenwala (1965)'s description can be modeled by adopting the constraint *HD$_{Ft}$≤{i,u} rather than *HD$_{Ft}$≤{e,o}. Similarly, Campbell & King (2011)'s and Modi (2013)'s descriptions can be explained by the constraint *HD$_{Ft}$≤{ə}.

For trisyllabic words, de Lacy (2002), Cardona (1965) and Doctor (2004) agree that stress is attracted to [a] from the default position, and [ə] repels stress from penult to antepenult. However, Cardona (1965) and Doctor (2004) distinguish [i] from [u]: [i] repels stress while [u] does not. Moreover, Adenwala (1965) claims that stress is not predictable in trisyllabic words (CV.CV.CV).

Essentially, Cardona (1965)'s and Doctor (2004)'s descriptions cannot be adequately modeled in Kenstowicz (1997)'s and de Lacy (2002, 2004, 2006)'s theories because they distinguish [i] from [u], though de Lacy (2006: 241-242) suggests that [i] is deleted in the majority of these environments.

Finally, Cardona & Suthar (2003)'s and Schiering & van der Hulst (2010)'s proposed sonority scales work for both disyllabic and trisyllabic words.

● *Syllable shape*

There are disagreements regarding whether syllable shape affects stress placement. Masica (1991) and Cardona & Suthar (2003) assert that stress assignment in Gujarati is influenced not only by vowel quality but also by syllable shape. However, no data is provided in the

descriptions to support their claims.

Other descriptions of syllable shape mainly focus on [ə]: when [ə] occurs in a closed syllable, it does not repel stress (Cardona 1965, Doctor 2004, Schiering & van der Hulst 2010). Stress assignment with respect to other vowels is not conditioned by syllable shape. For disyllabic words, when the first syllable contains [ə] and is closed, it is stressed unless the second syllable contains [a] (Cardona 1965, Doctor 2004, Schiering & van der Hulst 2010). However, Modi (2013) says that the closed syllable always attracts stress irrespective of vowel sonority.

(8)   Stress conditioned by syllable shape: disyllables

References	Disyllables
Cardona 1965 Doctor 2004 Schiering & van der Hulst 2010	Cə́C.CV (V≠[a])
Modi 2013	CV́C.CV CV.CV́C

For trisyllabic words, Cardona (1965) and Doctor (2004) report that the penultimate syllable which contains [ə] is stressed when the penult is a closed syllable and the antepenult contains [ə]. However, in Schiering & van der Hulst (2010)'s description, [CəC] in penult position always receives stress, regardless of the vowel in the antepenult. Finally, Modi (2013) states that the penultimate closed syllable always gets stressed in trisyllabic words.

(9)   Stress conditioned by syllable shape: trisyllables

References	Trisyllables
Cardona 1965 Doctor 2004	Cə.Cə́C.CV cf. Cə́.Cə.CV(C)
Schiering & van der Hulst 2010	CV.Cə́C.CV (1st V≠[a]) cf. CV́.CəC.CV (Cardona 1965, de Lacy 2002)
Modi 2013	CV(C).CV́C.CV(C)

• *Free variation*

Many descriptions mention free variation of stress in certain environments. When [ə] appears in the penultimate syllable of disyllabic words, there is free variation between penultimate and ultima stress (Cardona 1965, Schiering & van der Hulst 2010). In trisyllables, if the antepenult is [a], there is free variation between initial and penultimate stress (Cardona 1965, Cardona & Suthar 2003, Schiering & van der Hulst 2010). It should be noted that this type of free variation occurs under the condition that the penultimate syllable is not [i] and [ə] in Cardona's description.

However, it is not clear whether there is any condition on the penultimate syllable in Cardona & Suthar (2003)'s and Schiering & van der Hulst (2010)'s descriptions. It is possible that the vowel cannot be [ə], based on the sonority hierarchy by Schiering & van der Hulst. Doctor (2004) points out two other cases of free variation. When a disyllabic word has [ə] in initial and final syllables, some speakers tend to stress the vowel interchangeably. When a trisyllabic word has antepenultimate and penultimate [i], they can be 'indifferently' stressed, which I interpret as meaning that either there is free variation, or there is no perceptible difference between the two.

(10)   Free variation

References	Free Variation
Cardona (1965) Schiering & van der Hulst (2010)	Cə́.CV ~ Cə.CV́ (V≠[a])
Cardona (1965) Cardona & Suthar (2003) Schiering & van der Hulst (2010)	Cá.CV.CV(C) ~ Ca.CV́.CV(C)
Doctor (2004)	Cə́.CəC ~ Cə.Cə́C
Doctor (2004)	Cí.Ci.CV ~ Ci.Cí.CV

• *Why is there disagreement?*

No description of Gujarati stress agrees with any other in all their details (Cardona (1965) and Doctor (2004) are almost identical but disagree with each other about free variation). While some reasons for this disagreement will be discussed here, it is important to emphasize that the goals and scope of this study do not require perfectly homogeneous descriptions. The present goal is to determine whether Gujarati has sonority-driven stress, and almost every description agrees that it does for disyllables involving [a]. So, the focus of this study will be on disyllables with [a].

One possible source of descriptive variation is diachronic change: after all, the descriptions range from Turner's in 1921 to Modi's in 2013. However, the descriptions show disagreement even if they are chronologically close.

Another obvious source of variation could be dialect. Some descriptions lack information about which Gujarati dialect they investigate (Masica 1991, Mistry 1997, Schiering & van der Hulst 2010, Campbell & King 2011, Modi 2013). The rest of the descriptions focus on the Ahmedabad dialect (Patel & Mody 1960, Cardona 1965, Adenwala 1965, Doctor 2004, de Lacy 2006), except for the work by Master (1925) in which the description is based on the Charotar dialect. However, as the discussion above indicates, even the descriptions of the Ahmedabad dialect disagree with each other. Of

course, it is possible that there are subdialects within the Ahmedabad dialect, or widespread idiolectal variation.

Unfortunately, looking at the metrical systems of closely related languages does not help clarify the Gujarati situation. The two most closely related documented Indo-Aryan languages are Delhi Hindi and Siraiki. While it is reported for both languages that stress distinguishes syllables with peripheral vowels from those with central vowels (Shackle 1976, Pierrehumbert & Nair 1996), peripheral vowels are significantly longer than central vowels (Shackle 1976:13), suggesting that an appropriate metrical analysis could refer to moraic quantity rather than sonority (e.g. Hayes 1995: ch.7, cf. Gordon 1999).

A final possibility is that the disagreements are due to the author's misperception of stress. To be specific, the discrepancies might in fact result from the impressionistic methodology in which investigators used different perceptual properties to identify the location of stress. Given that the authors' native languages (and perceptual systems) vary, this is a significant possibility, emphasized in recent work on stress (e.g. Bowern *et al*. in preparation on Yidiny, Tabain *et al*. 2014 on Pitjantjatjara). Section 4.5.2 contains further discussion.

To summarize, there have been many descriptions of Gujarati stress, and almost all disagree with each other. It is difficult to interpret the reason for this diversity. Perhaps stress varies significantly even within dialects, or perhaps the impressionistic methods used to determine stress were inadequate. Regardless, almost all of the descriptions agree that the default position of stress is the penult, that stress is influenced by the sonority of vowels in some way – specifically, almost all agree that stress seeks out [a], or avoids [ə], or does both. This sonority-sensitivity is the descriptive claim that will be pursued in the remainder

of this work.

4.2.3 Phonological evidence for metrical structure in Gujarati

Many phonological and morpho-phonological processes are potentially sensitive to heads. Typical stress sensitive phonological processes include vowel reduction (e.g. Crosswhite 2001), fortition (e.g. Bye & de Lacy 2008), and allophony (e.g. Beckman 1998). Stress sensitive morphological processes such as infixation (e.g. McCarthy 1982 on English expletive infixation), allomorphy (e.g. Kager 1996), and truncation (e.g. Benua 1995) are also found.

Stress-sensitive allophony is mentioned in several descriptions of Gujarati. The central vowel [ə] is realized as [ʌ] when it is stressed (Patel & Mody 1960, Lambert 1971, Nair 1979). Allophonic alternations between high peripheral and non-peripheral vowels [í ú]~[ɪ ʊ] are also reported to be conditioned by stress (Cardona 1965, de Lacy 2002): the non-peripheral allophones appear in non-final open syllables, except when they are stressed. Therefore, allophony provides extremely important evidence for the location of metrical heads. Unfortunately, allophony is the only stress-sensitive phonological process reported in previous descriptions (section 4.4.1 will present evidence that allophony does not in fact support the sonority-driven descriptions of stress, but instead is consistent with sonority-insensitive penultimate stress).

No stress-sensitive morpho-phonological or phonological processes (such as vowel reduction) other than the putative suffix -av mentioned above are identified in previous work (Turner 1921, Master 1925, Adenwala 1965, Cardona 1965, Mistry 1997, de Lacy 2002, Cardona & Suthar 2003, Doctor 2004, Schiering & van der Hulst 2010, Campbell &

King 2011, Modi 2013). Finally, intonational tunes may be sensitive to heads; this point is taken up in section 4.4.3.

Consequently, phonetic realization is the primary source of evidence for Gujarati metrical structure.

4.2.4 Phonetic realization of stress

A modular view of the phonological and phonetic components is adopted here (e.g. Keating 1985, Cohn 1998). The phonological output has metrical structure specified, and marks PrWd and foot head syllables, as well as non-head syllables of feet.

The phonetic module can realize heads and non-heads in a variety of ways. Stressed vowels can be realized with an excursion in fundamental frequency (F0), increased intensity, and increased duration. Examples are found in diverse languages: e.g. English (Fry 1955, 1958), Polish (Jassem *et al*. 1968), Chickasaw (Gordon 2004), Turkish (Levi 2005), and Kabardian (Gordon & Applebaum 2010). Other potential acoustic correlates of stress have come to light, such as vocalic peripheralization (or centralization of unstressed vowels) (Campbell & Beckman 1997, Gordon 2004), and lack of spectral tilt (Sluijter & van Heuven 1996).

The reports cited above indicate that there are a variety of different acoustic effects of stress, and not all cues are always used. Furthermore, Gordon (2004) shows that cues used can vary from speaker to speaker within the same language. In Chickasaw, some speakers use duration to mark the difference between primary and secondary stress, others use a combination of fundamental frequency and intensity, and one subject used only F0.

However, Gordon (2004: 23-25) makes two important observations. First, almost

all speakers use at least one of F0, intensity, and duration to distinguish primary and secondary stress. Second, the distinction for speaker Male 1 does not emerge from the measured parameters. As Gordon points out, such inter-speaker variation is atypical from a cross-linguistic standpoint.

Although previous descriptions of the phonetic realization of Gujarati stress are impressionistic, they are broadly consistent with the findings mentioned above. Stressed vowels are reported to have a longer duration (Pandit 1958, Adenwala 1965, de Lacy 2006, Modi 2013), raised F0 (de Lacy 2002, 2006), and greater intensity (de Lacy 2002) than unstressed vowels. When [a] is stressed, it is reported to have not only a longer duration (Lambert 1971) but also a higher intensity (Patel & Mody 1960). However, Campbell (1995: 209) asserts that stress is barely perceptible in the language.

For the present study, the general consistency of the phonetic realization of metrical heads discussed above is taken to suggest that stress in Gujarati is likely to be realized by at least one of increased duration, F0 excursion, vowel quality (F1, F2), and intensity, so it is these acoustic properties that are the primary focus of this chapter. The acoustic results reported below indicate that Gujarati has consistently penultimate stress rather than sonority-driven stress.

4.3 Methodology

4.3.1 Goal of the experiment

The goal of the experiment is to test whether there is sonority-driven stress in Gujarati. In particular, [a] is the focus of the experiment because most descriptions on sonority-driven

stress refer to [a] as attracting stress. Following the descriptions in section 4.2.2, two hypotheses were examined, as in (11).

(11)   Competing Hypotheses for Gujarati

   a. Sonority-Driven hypothesis

   Stress falls on the penult by default, but falls on a non-penultimate [a] when the penult contains a less sonorous vowel

   b. Penultimate hypothesis

   Stress always falls on the penult regardless of vowel sonority.

The motivation for the Sonority-Driven hypothesis is that almost every description of Gujarati stress asserts that [a] attracts stress (see references in section 4.2.2). The motivation for the Penultimate hypothesis is the observation that all the descriptions identify the penult as the default position for stress (see references in section 4.2.2).

   Forms such as [Ca.Ca], [Ca.Cψ], and [Cψ.Ca] play an essential role in disambiguating the two hypotheses because the two hypotheses predict different stress patterns. Here, the symbol 'ψ' ranges over [o, i, u].

(12)   Predicted stress patterns: [a]

Penultimate	Sonority-Driven	Comment
'Ca.Ca	'Ca.Ca	Identical forms
'Ca.Cψ	'Ca.Cψ	Identical forms
'Cψ.Ca	Cψ.'Ca	Different forms

   For ease of exposition, I will use the following abbreviations throughout the chapter.

$[a^a]$ and $[^aa]$ refer to the penultimate [a] and ultimate [a] in the form [Ca.Ca], respectively. $[a^\psi]$ refers to the [a] preceding other vowels, as in the form [Ca.Cψ], whereas $[^\psi a]$ refers to the [a] following other vowels, as in the form [Cψ.Ca].

To disambiguate the two hypotheses, $[^\psi a]$ plays a crucial role. The Penultimate hypothesis predicts that $[^\psi a]$ and $[^a a]$ should be acoustically very similar, if not identical – they are both final and non-heads. The sole difference is the identity of the penult's vowel – $[^\psi a]$ vs. $[a^a]$ and $[a^\psi]$. In contrast, the Sonority-Driven hypothesis predicts that $[^\psi a]$ should be acoustically distinct from $[^a a]$. After all, $[^\psi a]$ and $[^a a]$ are identical – they appear in the same position (ultima); they differ only in metrical headedness.

Furthermore, if the influence of position (penult vs. ultima) is factored out, other comparisons are predicted to be revealing. The Penultimate hypothesis predicts that $[a^a]$ and $[a^\psi]$ should be acoustically distinct from $[^\psi a]$, whereas the Sonority-Driven hypothesis predicts $[a^a]$, $[a^\psi]$, and $[^\psi a]$ should be acoustically similar.

In summary, in terms of acoustic similarity, the Penultimate hypothesis predicts that $a^a = a^\psi$, $^a a = {}^\psi a$, and $a^a/a^\psi \neq {}^a a/{}^\psi a$ (where '=' means acoustically similar, putting aside non-stress contextual influences); the Sonority-Driven Hypothesis predicts that $a^a = a^\psi = {}^\psi a$ and $a^a/a^\psi/{}^\psi a \neq {}^a a$.

Non-[a] vowels (i.e. [o, i, u]) in other positions are also treated differently under the two hypotheses. For ease of exposition, I will use $[\psi^\psi]$ and $[^\psi\psi]$ to refer to the penultimate and ultimate [ψ], respectively, in the form [Cψ.Cψ]. Moreover, $[\psi^a]$ refers to the vowel preceding [a] in [Cψ.Ca] while $[^a\psi]$ refers to the vowel following [a] in [Ca.Cψ].

(13)   Predicted stress patterns: other vowels

Penultimate	*Sonority-Driven*	*Comment*
'Cψ.Cψ	'Cψ.Cψ	Identical forms
'Cψ.Ca	Cψ.'**Ca**	Different forms
'C**a**.Cψ	'C**a**.Cψ	Identical forms

The Penultimate hypothesis predicts that [ψ^ψ] and [ψ^a] should be acoustically different from [^ψψ] and [^aψ] since the former two are in the penult and the latter two in the ultima. However, the Sonority-Driven hypothesis predicts that [ψ^ψ], the only metrical head, should be acoustically different from the non-heads [^ψψ], [ψ^a], and [^aψ].

4.3.2 Experiment design

A word-list was constructed by consulting with three native speakers of Gujarati (see Appendix C). Disyllabic words with the shape [Ca.Ca], [Ci.Ci], [Co.Co], and [Cu.Cu] were used to establish baselines for the acoustic realization of stressed and unstressed vowels. Other word types had the form [Ca.Cψ] and [Cψ.Ca]. [ɛ] and [ɔ] were not used because they have a restricted distribution and low frequency of occurrence (see section 4.2.1). My subjects reported that Hindi borrowings can end with [e], so the mid vowel [e] was also excluded in order to avoid potential confusion with Hindi words. [ə] was excluded because [ə] does not appear word-finally. The pairs allowed direct comparison of vowels in both putatively stressed and unstressed states (see section 4.3.1).

The first consonants were limited to aspirated and unaspirated stops [b^(h) d^(h) g^(h) p t^(h) k^(h)] to reduce influence on the following vowel's duration (van Santen 1992: 527-532) and the second consonant was a voiceless unaspirated or aspirated stop [p t^(h) k^(h)], to keep influence on the preceding vowel's duration relatively constant (Peterson & Lehiste 1960).

This stimulus structure not only facilitated identification of vowel boundaries but also minimized segmental effects on vowels (e.g. vowel lengthening before voiced consonants).

Trisyllabic words were excluded from this study. Since the consonants were limited to stops, the total number of *real* trisyllabic words compared with disyllabic words was very low. In practical terms, including trisyllabic words would require multiple comparisons of the same vowel in a variety of different prosodic positions, resulting in undesirably lengthy production tasks for the subjects.

There were ten tokens for words with the [Ca.Ca] shape and five tokens for words with the [Cψ.Cψ] shape. There were five tokens for words with the [Ca.Cψ] and [Cψ.Ca] shape. In sum, there were 55 stimuli in the experiment. No description provides information on word frequency in vernacular words. However, the informants who helped me compile the list reported that the words were all familiar to them and frequently used in everyday conversation. Loanwords from Hindi and English were excluded entirely.

Morphologically, Gujarati is an agglutinative language. Hence, some of the stimuli were composed of two morphemes instead of one, for example, [kap-o] 'a cut + masculine' and [kap-i] 'a cut + feminine'. Words with different parts-of-speech were used in the experiment, including nouns, verbs, and adjectives. Almost none of the previous descriptions report that morpheme boundaries affect stress assignment, and several explicitly include examples of multi-morphemic words showing sonority-sensitivity across such boundaries (e.g. Cardona 1965: 32-35). The only description of the relation between stress and affixes is found in Modi (2013: 160): the causative suffix *-av* takes the stress and reduces the length of the previous syllables irrespective of which vowel proceeds it, e.g. [kúd] 'jump'→ [kudáv]. The putatively stress-attracting *-av* suffix was excluded from this

study. In addition, both Cardona (1965: 35) and de Lacy (2002: 71) report that prefixes are outside the stress assignment domain. Therefore, prefixes were excluded from this study.

To test the productivity of stress assignment in Gujarati, wug words were used in the experiment (Berko 1958). Of the 55 stimuli, 11 were wug words. In particular, words with the shape [Cu.Cu] and [Cu.Ca] were relatively rare so a large number of wug words was used. The native vs. wug status of stimuli was examined in the statistical analysis and was found to have no effect.

Each word was placed in two frame sentences to control for phrase-final lengthening. All the words were put in sentence-medial position, as shown in (14). It was found that there were different pauses in the frame sentences: a pause before the target word in (14a) and a pause after the target word in (14b). From now on I will refer to the frame sentence (14a) as the 'post-pausal' context, and to (14b) as the 'pre-pausal' context. We will see that pause (or phrase-finality) affects some aspects of the acoustic realization of the final vowel (particularly duration). Three repetitions were collected, yielding a total of 330 tokens per speaker.

(14)   Two frame sentences

a. Post-pausal sentence

[tame   a   ʃabdə   ne   ____   kaho   tʃʰo]

 you   this   word   to   read tense-present

'You read this word ____.'

b. Pre-pausal sentence

[a   ʃabdə ____ kʰaɾekʰaɾ mastə   tʃʰe]

 this   word   really   interesting is

'This word ____ is really interesting.'

There were three recording sessions in this experiment. Participants read 70 stimuli and 15 fillers in each session. Colloquial filler sentences were employed to encourage subject's vernacular speech. Fillers were interspersed among the stimuli with a spacing of seven stimuli. Five fillers were introduced at the beginning of each session to take into account the effects of any initial nervousness the subject might have about the task. The order of the stimuli was pseudo-randomized and counter-balanced in each session.

4.3.3 Participants

Four male and one female native Gujarati speakers participated in the experiment. Their ages ranged from 19 to 24 years. All had recently moved to the United States and still communicated in Gujarati on a daily basis. Except for one participant who was from a Gujarati community in Mumbai, the other participants were from Gujarat State in India. All participants spoke the standard dialect of Gujarati, including the varieties spoken in Ahmedabad, the former capital of Gujarat, and Mumbai. None of the participants had linguistic training or a history of speech impairments. They were naive as to the goal of the experiment. The participants received nominal monetary compensation for their participation.

4.3.4 Procedure

The experiment was performed at the Phonology and Field Research Laboratory (Phonolab) at Rutgers University. Participants were recorded while sitting in a sound-attenuated booth and wearing an AKG C420 head-worn microphone with a behind-the-neck headband in order to keep the microphone at a constant distance from the mouth. The microphone was connected to an ART MPA Gold pre-amplifier, which output to an M-Audio Delta 1010LT sound card. The recording was done using GoldWave v6. 10 at a 44.1k Hz sampling rate and 16-bit quantizing rate in mono.

Prior to the experiment, the participants were asked to fill out a circadian rhythm questionnaire adapted from Smith *et al*. (1989) which elicited information concerning their circadian rhythm types. The purpose was to ensure participants felt at their best - when they felt most alert and awake in the experiment. All of the participants belonged to the 'intermediate' type so the experiment sessions were scheduled around noon. Instructions for the day before the experiment were e-mailed to participants to make certain they kept to their daily routines.

Participants were presented with words written in Gujarati script on a computer screen. Participants were presented with some of the target words on the screen before the recording sessions began to familiarize them with the Gujarati font since Gujarati script is normally written by hand.[4] The words were presented individually without frame sentences; that is, participants had to generate the two predetermined sentences during the experiment. The recording sessions were conducted individually. Participants read the words when they

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[4] Recordings of 30 sentences (from different repetitions and frame sentences) were selected from each speaker and sent to a research assistant who is also a native speaker of Gujarati. The research assistant was asked to judge the naturalness of those sentences, and specifically to comment on whether the subjects appeared to hyper-articulate. The research assistant reported that all the sentences sounded natural to her.

were ready, at a normal conversational speed. Breaks were given after each recording session. Some effort was expended in ensuring that the subjects employed their vernacular. Specifically, a Gujarati research assistant engaged the participants in vernacular speech by having conversations with them during the breaks about mundane daily activities. The goal was to ensure the data were elicited from the vernacular L1 phonological module of each participant (de Lacy 2014: 13-16). The Gujarati research assistant was informed of the experiment's purpose and the methods used in the experiment. To avoid participant exhaustion, four of the five participants engaged in the experiment over two different days, while one participant – who showed little tiredness – finished the experiment in one day. The experiment was structured so that the potential effect of intra-speaker differences in two separate sessions was minimized.

4.3.5 Measurements

Acoustic correlates of stressed/unstressed vowels were measured, including duration, F0, F1, F2, and intensity. Using Praat TextGrids (Boersma & Weenink 2016), four intervals were labeled for each file: the extent of the first and second vowels of the target word in the two frame sentences.

The left boundary of each vowel was marked at the beginning of the first non-deformed periodic waveform. The right boundary was identified as the end of the second formant, with the help of the third formant when the end of the second formant continued into closure (Turk *et al*. 2006: 7). The segmentation was initially performed by two groups of three research assistants. The results were compared within each group to minimize human error. Finally, the author examined the TextGrids and made corrections only when

(a) wrong vowels were labeled, (b) consonants were mislabeled as part of a vowel, and (c) the right boundary of vowels was noted by the research assistants as uncertain; otherwise no changes were made.

The labeled sound files were then run through customized Praat scripts to obtain acoustic measures. Duration and mean intensity were extracted from the TextGrids. For F0, F1, and F2, the midpoint of each vowel was calculated. The purpose was to get the steady point of the vowel. The results were then saved to an Excel file for subsequent analysis.

4.3.6 Statistical methods

In the following sections, I determine whether each of the acoustic measures was a statistically significant correlate of stress of [aᵃ], [ᵃa], [aᵠ], and [ᵠa] in Gujarati. The values of each measure were analyzed using linear mixed-effects models. These were implemented in R (R Development Core Team 2016) using the *lmer()* function of the *lme4* package (Bates *et al*. 2015). For each vowel ([a], [o], [i], [u]), five separate models were fitted to determine the acoustic correlates of Gujarati stress. The acoustic measures (F1, F2, intensity, F0, duration) were the dependent variable. For each model, vowel in different positions (e.g. [aᵃ], [ᵃa], [aᵠ], [ᵠa]) and frame sentences (post-pausal sentence, pre-pausal sentence) were set as fixed effects. An additional variable, aspiration, was added to the model on duration to test whether aspiration has an influence on vowel duration. Speaker and word were included as random effects. The interaction between the fixed effects (vowel positions and frame sentences) was tested using the *anova()* function to compare likelihood between models (Baayen 2008). Random slopes for the by-speaker and by-word effects of vowel positions and frame sentences were specified for each model (Barr *et al*.

2013). In order to test whether the wug words were treated differently from native words, different linear mixed-effects models were applied to the stimuli containing wug and real words ([Ca.Ca], [Co.Ca], [Ci.Ca], [Cu.Ca], [Cu.Cu]). For each model, the acoustic measures (F1, F2, intensity, F0, duration) were the dependent variable, and wug (nonce words, real words) was set as the fixed effect. Random slopes for the by-speaker and by-word effects of wug words were specified for each model. P-values were obtained using the *summary()* function of the *lmerTest* package (Kuznetsova *et al.* 2016). It was found that wug words were not different from real words acoustically, with all p-values greater than 0.106.

For the F1 model on [i], the F2 models on [a], [i], and [u], and the F0 model on [o], the interaction term was not found to significantly improve model fit. As for random slope structure, the F1 model on [i], the F2 models on [o] and [u], the intensity model on [a], the F0 model on [i], and the duration models on [a], [i], and [u] failed to converge. So the next-best models were chosen based on the likelihood ratio test mentioned above. The duration model on [u] included by-speaker random slope for the effect of vowel positions, and by-word random slope for the effects of vowel positions and frame sentences. Other models included by-speaker random slope for the effects of vowel positions and frame sentences, and by-word random slope for the effect of frame sentences. Visual inspection of residual plots did not reveal any obvious deviations from homoscedasticity or normality. Crucially, I report multiple pairwise comparisons for each vowel, which is obtained using the *pairwise()* function of the *lsmeans* package (Lenth 2016). The estimates were based on the Tukey Honestly Significant Difference (Tukey HSD) method. I report t-values as well as p-values provided in the model output. When the interaction term is not significant for the

model (namely, the vowel does not behave differently in different frame sentences), I report multiple pairwise comparisons for both frame sentences.

4.3.7 Predicted stress patterns

Following the previous descriptions, two hypotheses were entertained: the Penultimate stress hypothesis and the Sonority-Driven stress hypothesis. Assuming stress is realized by at least some acoustic property, the Penultimate hypothesis in (15) and Sonority-Driven hypothesis in (16) make clear predictions for the acoustic realization of [a] in various syllable positions. These predictions are summarized in formulaic terms below.

(15)   The Penultimate hypothesis

[Ca.Ca]   ===> $[a^a] \neq [^aa]$

[Ca.Cψ]   ===> $[a^a] = [a^\psi] \neq [^\psi a]$

[Cψ.Ca]   ===> $[^aa] = [^\psi a]$

(16)   Sonority-Driven hypothesis

[Ca.Ca]   ===> $[a^a] \neq [^aa]$

[Ca.Cψ]   ===> $[a^a] = [a^\psi] = [^\psi a]$

[Cψ.Ca]   ===> $[^aa] \neq [^\psi a]$

4.4 Results

This section presents results from the experiment on [a]'s alleged stress attraction in Gujarati. Sections 4.4.1, 4.4.2, 4.4.3, and 4.4.4 present results for F1/F2, intensity, F0, and

duration, respectively.

Recall in section 4.3.1, predictions are made based on vowels in different positions. Using the schema in (17) below, both the Sonority-Driven and Penultimate theories predict that the penult is stressed in [Ca.Ca], [Ca.Cψ], and [Cψ.Cψ] words, but differ for [Cψ.Ca] words; note that I use 'ψ' to stand for every vowel *except for* [a] here (i.e. [o, i, u]). I will refer to this schema throughout the following discussion.

(17)   Schematic word structures (ψ = [o, i, u])

   [Caᵃ.Cᵃa]   [Cψᵠ.Cᵠψ]

   [Caᵠ.Cψ]   [Cψᵃ.Ca]

   [Cψ.Cᵠa]   [Ca.Cᵃψ]

4.4.1 F1 and F2

This section presents the F1 and F2 results. Recall that allophonic alternations between high peripheral and non-peripheral vowels [í ú]~[ɪ ʊ] are claimed to be conditioned by stress (Cardona 1965, de Lacy 2002). So, stress could be reasonably expected to affect vowel quality: [a] is expected to have different realization under the condition of stress. If stress is sonority-driven, then the [ᵠa] in [Cψ.Ca] should be stressed and therefore more peripheral than [ᵃa] in [Ca.Ca], and potentially the same quality as the stressed [aᵃ] (as long as no other non-stress factors interfere). If stress falls on the penultimate syllable, [ᵠa] should be unstressed and thus have a similar vowel quality to [ᵃa]. Therefore, [ᵠa] plays an important role in disambiguating the two hypotheses.

Results from the linear mixed-effects model show that [ᵠa] and [ᵃa] belong to the

same category while [aᵃ] and [aᵠ] form another one.

Figure 4.1: Vowel plot for [a] vowels in the post-pausal (left panel) and pre-pausal (right panel) contexts.
(● = aᵃ, ▲ = aᵠ, ○ = ᵃa, △ = ᵠa)
The ellipsis delineates one standard deviation from the mean value.

Under the Sonority-Driven hypothesis, [ᵠa] should have a different quality from [ᵃa] because [ᵠa] is stressed while [ᵃa] is unstressed. In contrast, the Penultimate-stress hypothesis predicts that [ᵠa] and [ᵃa] should have the same quality as both are unstressed.

Focusing on F1, [ᵠa] overlaps with [ᵃa] (t=-0.501, p=0.9558). This suggests that the centralized [ᵠa] is actually unstressed: if [ᵠa] is stressed, it should be the same as [aᵃ] and [aᵠ] in terms of vowel height. The fact that [ᵠa] overlaps with the unstressed [ᵃa] is consistent with the hypothesis that stress falls on the penult, rather than on [a]. The Penultimate stress hypothesis is further supported by comparing [ᵠa] with [aᵃ] and [aᵠ]. If [a] attracts stress, [ᵠa] should be identical to the stressed [aᵃ] and [aᵠ] according to the Sonority-Driven hypothesis. However, [ᵠa] differs from [aᵃ] and [aᵠ] in that [ᵠa] has a lower F1 than the stressed [aᵃ] and [aᵠ] (for [ᵠa] vs. [aᵃ]: t=4.938, p=0.0105; for [ᵠa] vs.

[aᵝ]: t=4.387, p=0.0157).

The F1 pattern for [a] vowels is the same across different frame sentences. In the pre-pausal context, [ᵠa] is significantly more centralized than the stressed [aᵠ] and [aᵃ], and has the same height as the unstressed [ᵃa] (for [ᵠa] vs. [aᵠ]: t=3.567, p=0.0461; for [ᵠa] vs. [aᵃ]: t=3.995, p=0.0329; for [ᵠa] vs. [ᵃa]: t=-0.676, p=0.9028).

As for F2, I find no evidence to support the Sonority-Driven hypothesis. If stress is sonority-driven, [ᵠa] should have a lower F2 than [ᵃa] and the same F2 as [aᵠ] and [aᵃ]. However, this is not the case. In both contexts, the crucial vowel [ᵠa] makes no distinction between [aᵃ] and [ᵃa] (for [ᵠa] vs. [aᵃ]: t=-1.25, p=0.6074; for [ᵠa] vs. [ᵃa], t=0.478, p=0.9632), and [ᵠa] is marginally significantly more fronted than [aᵠ] (t=-2.823, p=0.0395).

In short, the multiple pairwise comparisons of the mean F1 values of [a] confirm the Penultimate hypothesis instead of the Sonority-Driven hypothesis.
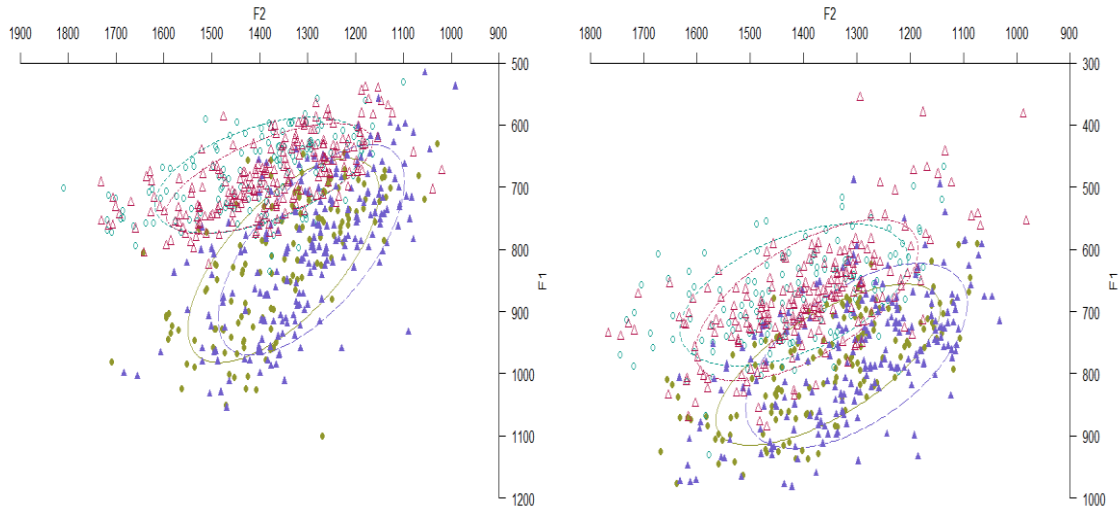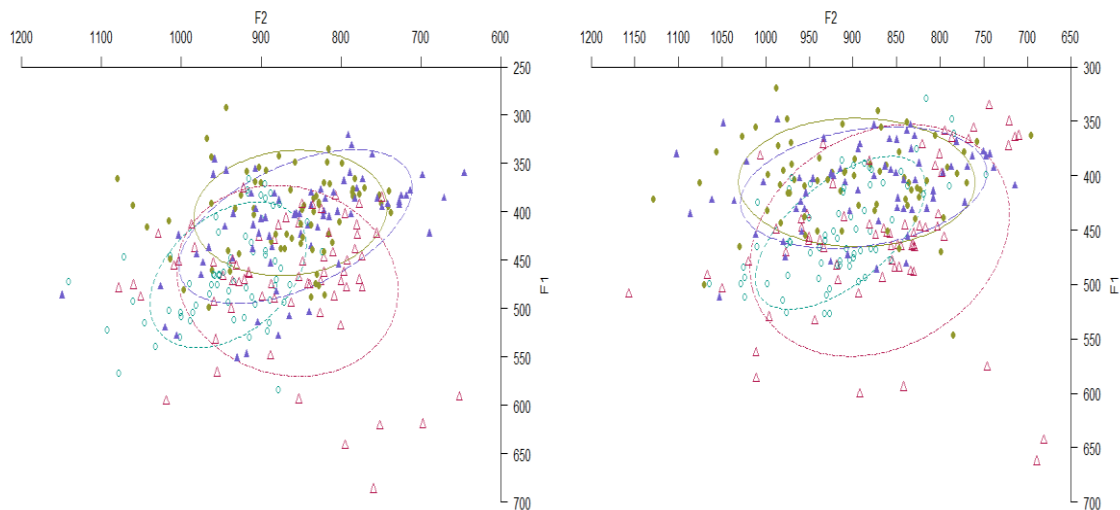

Figure 4.2: Vowel plot for [o] vowels in the post-pausal (left panel) and pre-pausal (right panel) contexts.
(● = oᵒ, ▲ = oᵃ, ○ = ᵒo, △ = ᵃo)
The ellipsis delineates one standard deviation from the mean value.

If the Penultimate hypothesis is true and vowel height is conditioned by stress in Gujarati, the same pattern should be found for other vowels. The vowels [o, i, u] in the post-pausal and pre-pausal contexts are plotted separately, as shown below. The numbered vowels in the plot indicate vowels in different positions (see 17).

The F1 pattern of [o] is in line with the Penultimate hypothesis. If stress is sonority-driven, [ᵃo], [oᵃ], and [ᵒo] should be unstressed, having the same vowel quality. [oᵒ] should be the only stressed vowel and has a distinct vowel quality from [ᵃo], [oᵃ], and [ᵒo]. In the post-pausal context, no statistical distinction was found between [ᵃo] and [ᵒo] (t=-0.513, p=0.9525), and the same for [oᵃ] and [oᵒ] (t=-1.411, p=0.5206). Specifically, [ᵃo] and [ᵒo] have higher F1 values than [oᵃ] and [oᵒ]. Moreover, the F1 pattern of [o] is the same in the pre-pausal context (for [ᵃo] vs. [ᵒo]: t=-0.451, p=0.9667; for [oᵃ] vs. [oᵒ]: t=-0.611, p=0.9261).

As for F2, no statistical distinctions were found among pairs in either context (all p-values greater than 0.1961), except that the difference between [ᵒo] and [oᵒ] in the post-pausal context was marginal (t=-3.495, p=0.0614). If sonority-driven stress exists, [oᵒ] should have a lower F2 than [ᵃo], [oᵃ], and [ᵒo]. If stress falls on the penultimate syllable, [oᵒ] and [oᵃ] together should have a lower F2 than [ᵒo] and [ᵃo]. However, the facts suggest that F2 is not able to differentiate the two hypotheses.

For [i], the mean F1 values seem to suggest that stress falls on the penultimate syllable ([iⁱ]: 286 (29) Hz, [ⁱi]: 311 (47) Hz, [iᵃ]: 273 (24) Hz, [ᵃi]: 313 (46) Hz). That is, [ᵃi] and [ⁱi] are more centralized than [iᵃ] and [iⁱ], indicating that [ᵃi] and [ⁱi] are unstressed. However, the statistical analysis does not show any significant differences, with all p-values greater than 0.2032. It is possible that the participants in this study have a smaller

vowel space so that the quality distinction between stressed and unstressed [i]s is not statistically significant.

As for F2, [i] displays the same pattern that [o] does. That is, there is almost no F2 distinction between each pair in both contexts, with all p-values greater than 0.1107 ([i^i]: 2411 (217) Hz, [^{i}i]: 2451 (227) Hz, [i^a]: 2419 (235) Hz, [^{a}i]: 2484 (241) Hz).

Finally, [u] in the post-pausal context displays a similar F1 pattern as [o] and [i] ([u^u]: 324 (34) Hz, [^{u}u]: 364 (43) Hz, [u^a]: 333 (36) Hz, [^{a}u]: 373 (44) Hz). Namely, [^{a}u] and [^{u}u] have a higher F1 compared to [u^u] and [u^a] (for [^{a}u] vs. [u^u]: t=-5.495, p=0.0003; for [^{a}u] vs. [u^a]: t=-3.947, p=0.0065; for [^{u}u] vs. [u^u]: t=-5.49, p=0.0022; for [^{u}u] vs. [u^a]: t=-3.339, p=0.0348). In other words, [^{a}u] and [^{u}u] are more centralized than [u^a] and [u^u]. On the other hand, the multiple comparisons of [u] in the pre-pausal context broadly show no significant difference, with all p-values greater than 0.0921 ([u^u]: 335 (32) Hz, [^{u}u]: 346 (42) Hz, [u^a]: 336 (31) Hz, [^{a}u]: 356 (38) Hz). The p-value for the pair [^{a}u] vs. [u^u] is 0.0196, and [^{a}u] is more centralized than [u^u], which is expected. It should be noted that [u]'s F1 and F2 are too close to each other, so Praat was unable to correctly identify the vowel formants. It is not practical to examine and then exclude the problematic data one by one. So the F1 and F2 patterns reported here may not reflect the real situation.

As for F2, none of the pairwise comparisons show any differences, with all p-values greater than 0.2061 ([u^u]: 873 (114) Hz, [^{u}u]: 796 (113) Hz, [u^a]: 776 (121) Hz, [^{a}u]: 811 (130) Hz). The F2 pattern of [u] is consistent with the F2 patterns of [o] and [i].

In short, the F1 outcomes from [a], [o], and perhaps [i] and [u] support the Penultimate hypothesis. Vowels in the ultima are generally more central than vowels in the penult. To be concise, the high vowels [i, u] and mid vowel [o] are lowered while the low

vowel [a] is raised when they are unstressed. I conclude that F1 serves as an acoustic cue for stress in Gujarati. This shift in F1 is not accompanied by an overall significant change in F2.

The comparison of vowel quality between post-pausal and pre-pausal sentences suggests that vowel quality in Gujarati is probably not conditioned by duration. Typically, changes in the vowel space for unstressed vowels are discussed in terms of undershoot or vowel reduction (Lindblom 1990). It is then conceivable that the reduced vowel space in Gujarati is because of the short duration of unstressed vowels. To be specific, articulatory targets may not be fully reached since there is insufficient time for articulatory movement. As I will discuss in the following section, the duration of the stimuli (especially the final syllable) in pre-pausal sentences are lengthened due to phrase-final lengthening. If the reduced vowel space in Gujarati is actually an articulatory undershoot, such phonetic effect should be erased for the stimuli in the pre-pausal sentences. However, results from the linear mixed-effects models on F1 reveal that the vowel height pattern is identical between both frame sentences, except for few vowels. Therefore, I conclude that vowel quality in Gujarati has no relation with undershoot (see Garellek & White 2015 for a similar finding in Tongan).

Changes in vowel quality as a function of stress are often found in other languages. Cross-linguistically, many languages tend to centralize unstressed vowels (see Crosswhite 2001). The reduction could be either phonological (a category shift) or phonetic (a gradient change). In English, vowels undergo a categorical shift to schwa when they are unstressed (Bolinger 1958, Fry 1965). In Chickasaw, unstressed vowels [a, o, i] are more centralized than vowels with primary and secondary stress (Gordon 2004). The centralization of

unstressed vowels is achieved by adjusting either F1 or F2 to reduce the vowel space. The reduction in Chickasaw is a gradient process rather than a category shift. In Garellek & White (2015)'s work on Tongan stress, they discover that unstressed vowels have shorter durations than vowels with primary stress. So, a reduced vowel space for unstressed vowels is expected. However, the pattern found in Tongan is not subject to undershoot and a reduced vowel space. Unstressed vowels consistently have higher F1 than their stressed counterparts, but the size of the vowel space is comparable for stressed and unstressed vowels. They attribute this unique vowel space shift (lowering of unstressed vowels) to the maintenance of perceptual clarity. That is, the contrast between stressed and unstressed vowels is enhanced without sacrificing the vowel quality contrast. However, Gordon & Applebaum (2010) argue that in Turkish Kabardian, although unstressed schwa and the central vowel [ɐ] have a lower F1 than their stressed counterparts, this apparent vowel space shift is due to coarticulation with surrounding consonants with a coronal primary or secondary articulation. For example, the unstressed schwa is raised because [s] precedes the target schwa in the root [bəsəm]. The tongue is raised for the coronal and must lower to assume the canonical position for schwa. However, there is insufficient time to reach the target schwa since unstressed vowels in Turkish Kabardian have shorter duration. This is then a result of phonetic undershoot. They conclude that changes in vowel quality in Turkish Kabardian do not function as a cue for stress.

Turning to Gujarati, the reduced vowel space for unstressed vowels is in keeping with the centralization type of reduction. That is, high vowels are lower and low vowels are higher. Interestingly, the mid vowel [o] is lowered when it is unstressed. This is contrary to Gordon (2004)'s finding in Chickasaw in which the unstressed mid vowel [o] is raised.

Moreover, Gujarati does not show the Tongan pattern found by Garellek & White (2015). That is, the unstressed vowels in Gujarati occupy a compressed space compared to the stressed vowels. Finally, the possibility that the F1 lowering of [a] is due to coarticulation with adjacent coronal consonants is excluded. Recall that the consonants used in this study are not solely limited to coronals (see section 4.3.2). If [a] is lowered because of adjacent coronals, the lowering effect should be erased when the surrounding consonants are bilabials and velars. A one-way ANOVA was performed to determine whether [ᵃa] (i.e. [tᵃa], [pᵃa], [kᵃa]) and [ᵠa] (i.e. [tᵠa], [pᵠa], [kᵠa]) have a lowered F1 when the onset is a coronal, rather than a bilabial or velar. The result shows that there is no significant difference between [ᵃa]'s F1 with different onsets (For [tᵃa]: F1=682 (74); For [pᵃa]: F1=689 (79); For [kᵃa]: F1=665 (62); $F_{(2,287)}=2.783$, $p=0.064$). [kᵃa] has a lower mean F1 than [tᵃa] and [pᵃa]. Furthermore, there is no significant difference between [ᵠa]'s F1 with different onsets (For [tᵠa]: F1=690 (76); For [pᵠa]: F1=681 (65); For [kᵠa], F1=675 (70); $F_{(2,440)}=1.886$, $p=0.153$). If the F1 lowering of [a] is really due to coronal onsets in Gujarati, we would expect [a] with a coronal onset to have a significantly higher F1 than [a] with bilabial and velar onsets. However, this is not the case. The pattern found here is in contrast to Gordon's finding in Turkish Kabardian. Thus, [a] is lowered due to the lack of stress, rather than surrounding coronals.

Finally, one might wonder whether the F1 pattern results from domain-initial strengthening. Studies on domain-initial strengthening indicate that segments which are not strictly local to the initial prosodic boundary are less likely to display articulatory and acoustic properties of domain-initial strengthening (e.g. Fougeron & Keating 1997, Cho & Keating 2001, Keating et al. 2003, Cho & Keating 2009, Georgeton & Fougeron 2014).

When non-local segments did show effects of domain-initial strengthening, they were more likely to be found initially in higher prosodic domains (e.g. Intonational Phrase/Utterance). In the current experiment, the penultimate vowels are not strictly local to the left boundary of a word; they are always preceded by a voiceless stop. They are also not close to a high-level prosodic boundary; while they are near a Prosodic Word boundary, domain-initial strengthening is not robust at the Prosodic Word level, as seen in the previous studies. Finally, the F1 pattern (peripheralization vs. centralization) is seen in both post-pausal and pre-pausal contexts, suggesting that F1 is not conditioned by domain-initial strengthening. Therefore, the possibility that domain-initial strengthening explains the properties of penultimate vowels reported here is relatively low.

In summary, [a]'s height varies with position: it is more centralized in final syllables. This is not consistent with the Sonority-Driven hypothesis, unless stress has no impact at all on vowel height. In contrast, it is consistent with the Penultimate hypothesis. Results from other vowels also support the Penultimate hypothesis. The final vowels are generally more centralized. Finally, the reduced vowel space for unstressed vowels is in line with the centralization type of reduction.

4.4.2 Intensity

This section explores whether intensity distinguishes stressed and unstressed vowels in Gujarati. According to Patel & Mody (1960) and de Lacy (2002), [a] has greater intensity when it is stressed. Following this prediction, [$^\psi$a] in [Cψ.Ca] should have a higher intensity under the Sonority-Driven hypothesis but a lower intensity under the Penultimate hypothesis. I report the results in the post-pausal and pre-pausal contexts separately, as in

Figure 4.3.
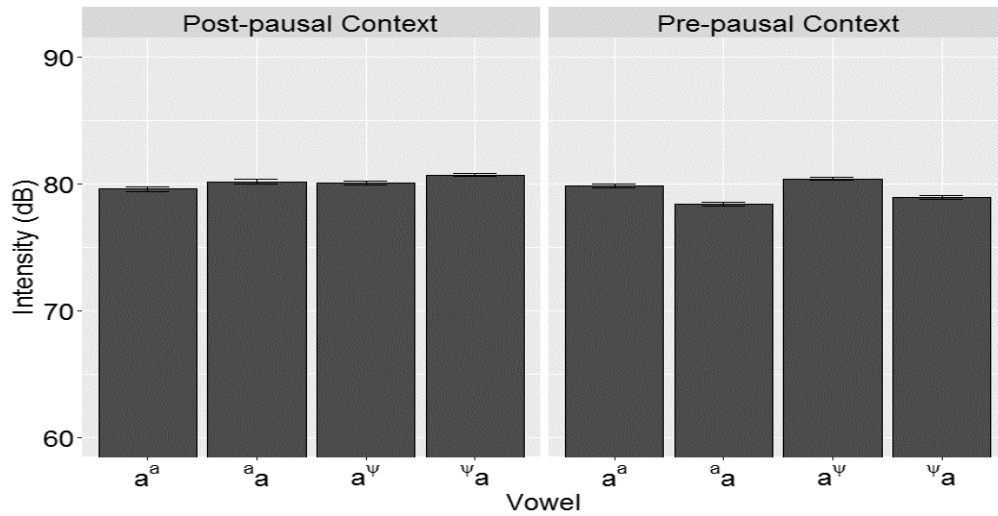
Figure 4.3: Intensity differences between [a] vowels.
Error bars represent standard error of the mean.

The intensity patterns of [a] in different contexts do not clearly support either one of the hypotheses. In the post-pausal context, there is no significant difference between these vowels. That is, [$^\Psi$a] has the same intensity value as [a^a], [^{a}a], and [a$^\Psi$] (for [$^\Psi$a] vs. [a^a]: t=-1.648, p=0.4325; for [$^\Psi$a] vs. [^{a}a], t=-1.743, p=0.3215; for [$^\Psi$a] vs. [a$^\Psi$]: t=-0.878, p=0.8166). If intensity is a correlate of stress in Gujarati, [$^\Psi$a] is expected to have a higher intensity value than [^{a}a] under the Sonority-Driven hypothesis. However, [$^\Psi$a] has the same intensity value as [^{a}a]. In the pre-pausal context, [$^\Psi$a] also has the same intensity value as [a^a], [^{a}a], and [a$^\Psi$] (for [$^\Psi$a] vs. [a^a]: t=1.307, p=0.5933; for [$^\Psi$a] vs. [^{a}a], t=-1.708, p=0.3386; for [$^\Psi$a] vs. [a$^\Psi$]: t=2.392, p=0.1830). In short, results from both frame sentences suggest that intensity is probably not a relevant acoustic cue for stress in Gujarati.

Similarly, results from other vowels do not clearly support either hypothesis. If stress in Gujarati is sonority-driven, [$^\Psi\psi$], [ψ^a], and [$^a\psi$] should have lower intensity than

[ψᵠ], since [ψᵠ] is the only stressed vowel. If stress falls on the penultimate syllable, [ᵠψ] and [ᵃψ] should have lower intensity than [ψᵠ] and [ψᵃ] because [ᵠψ] and [ᵃψ] are in the ultimate position.

For [o] in the post-pausal context, [oᵒ] does not differ from [ᵒo], [oᵃ], or [ᵃo] in terms of intensity, with all p-values greater than 0.1319 ([oᵒ]: 80.5 (2.4) dB, [ᵒo]: 81.7 (2.4) dB, [oᵃ]: 79.3 (2.6) dB, [ᵃo]: 80.3 (2.6) dB). So the Sonority-Driven hypothesis is not supported. As for the Penultimate hypothesis, [ᵒo] and [ᵃo] do not have significantly lower intensity value than [oᵒ] and [oᵃ], with all p-values greater than 0.1297. So the Penultimate hypothesis is not supported, either. In the pre-pausal context, none of the comparisons show statistical differences, with all p-values greater than 0.0842 ([oᵒ]: 80.2 (2.2) dB, [ᵒo]: 79.8 (2.8) dB, [oᵃ]: 78.9 (2.5) dB, [ᵃo]: 78.8 (2.6) dB). Therefore, the intensity pattern of [o] in the pre-pausal context does not support either hypothesis.

A similar pattern is observed for [i]. In the post-pausal context, each comparison is found to be non-significant, with all p-values greater than 0.0506 ([iⁱ]: 76 (3.5) dB, [ⁱi]: 77.6 (2.6) dB, [iᵃ]: 75.3 (4.2) dB, [ᵃi]: 76 (2.4) dB). Notice that the difference between [iᵃ] and [ⁱi] is borderline (t=3.033, p=0.0506). However, [ⁱi] has a higher intensity value than [iᵃ], which is the opposite of what is expected under both hypotheses, if intensity is a cue to stress. In the pre-pausal context, no overall significant difference is found among each pair, with all p-values greater than 0.3827 ([iⁱ]: 76 (3.4) dB, [ⁱi]: 76.1 (3.4) dB, [iᵃ]: 75.4 (3.4) dB, [ᵃi]: 75 (2.6) dB). Similarly, this result is not predicted by either hypothesis.

Finally, [u] displays a similar pattern as other vowels. In both contexts, none of the multiple comparisons reach statistical significance, with all p-values greater than 0.2972 (for [u] in the post-pausal context: [uᵘ]: 79.1 (3.3) dB, [ᵘu]: 79 (3.2) dB, [uᵃ]: 78 (3.4) dB,

[ᵃu]: 79.2 (3.3) dB; for [u] in the pre-pausal context: [uʷ]: 79.2 (2.8) dB, [ʷu]: 78 (3.4) dB, [uᵃ]: 77.7 (3.2) dB, [ᵃu]: 77.9 (3.7) dB). In short, results from [u] suggest that intensity does not provide evidence for either one of the hypotheses.

Cross-linguistically, greater intensity functions as an acoustic correlate of stress in many languages, including English (Lieberman 1960), Pirahã (Everett 1998), Chickasaw (Gordon 2004), and Tashlhiyt Berber (Gordon & Nafi 2012). Unlike other languages, Gujarati does not use intensity as a cue to stress. The vowel-to-vowel comparisons do not show a significant difference. Since it has been established that the just noticeable difference (JND) in sound intensity for the human ear is about 1 dB (Harris 1963), it is probable that the intensity differences in Gujarati are not perceptually significant given the similar mean and standard deviation for each pair (e.g. for [a] in the post-pausal context: [aᵃ]: 79.6 (2.2) dB, [ᵃa]: 80.2 (2) dB, [aʷ]: 80.1 (2.1) dB, [ʷa]: 80.7 (2) dB; for [a] in the pre-pausal context: [aᵃ]: 79.9 (2.1) dB, [ᵃa]: 78.4 (2.2) dB, [aʷ]: 80.4 (2) dB, [ʷa]: 79 (2.2) dB).

In sum, comparing the intensity values of [a] does not confirm either the Sonority-Driven hypothesis or the Penultimate hypothesis; vowels in different positions do not make intensity distinctions in most cases. Based on the multiple vowel intensity comparisons, I conclude that Gujarati does not use intensity as a cue of stress, differing from the other languages cited above.

4.4.3 F0

The most significant influence on F0 in Gujarati is intonation. In both frame sentences, the target word has a rising (LH) contour, as shown in Figures 4.4 and 4.5. Speech rate and

pitch range varied from speaker to speaker, so they were accounted for by normalizing

actual time and F0 contours using the Prosody Pro script for Praat (Xu 2013).[5]
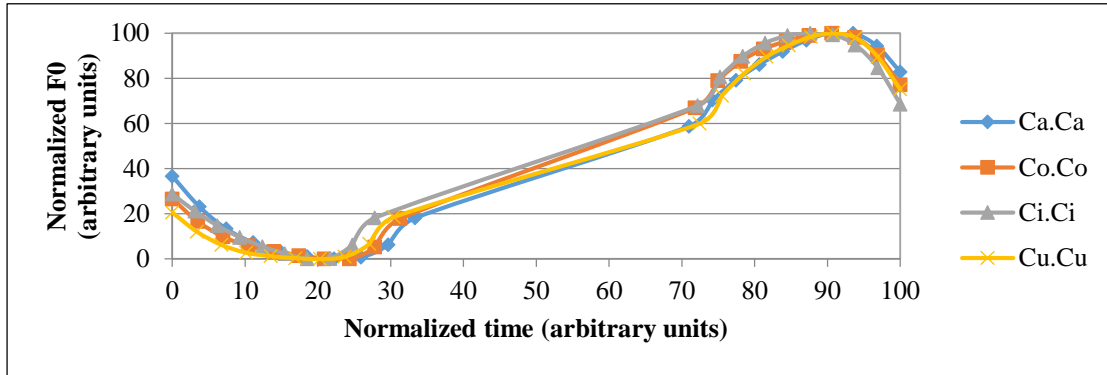
Figure 4.4: LH intonation melody in the post-pausal context.
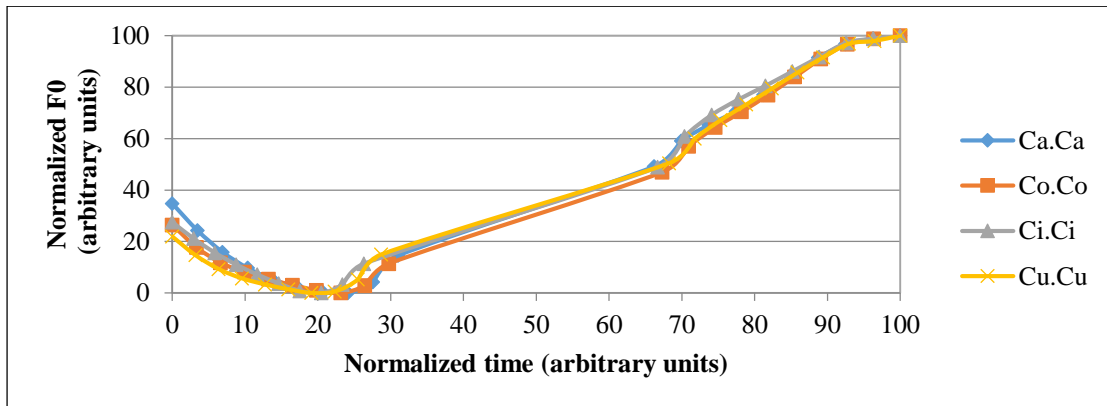
Figure 4.5: LH intonation melody in the pre-pausal context.

In both figures, the dotted parts indicate the normalized pitch track of the two target vowels.

The straight line connecting both vowels represents the onset consonant and its closure of

the second syllable. As will be discussed in next section, vowels in the pre-pausal context

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[5] The F0 contours and actual time were normalized with each interval divided into ten points. There are 20 points for each word since there are two vowels. First, the time of each point across all words in the same shape was averaged. The difference between each point and the starting point was divided by the difference between the starting and end points. The results were then multiplied by 100 to turn them into percentages. As for F0, the F0 of each point across all words in the same shape was averaged. The difference between each F0 point and the minimum F0 point was divided by the difference between the maximum and minimum F0 points. The results were then multiplied by 100 to turn them into percentages.

are lengthened due to phrase-final lengthening. So, the pitch track of the second vowel in the pre-pausal context starts earlier than that of the second vowel in the post-pausal context. Notice that for the second vowel in the post-pausal context, there is a dip at both ends of the pitch track. It is possible that the pitch is lowered because of the adjacent stops. However, this pattern is not seen in the pre-pausal context. As mentioned before, there is a significant pause immediately following the target word in the pre-pausal context. So, the reason that the end of the pitch is not lowered is probably due to the absence of the consonant effect.

There are three possible interpretations of this F0 contour. One is that it realizes a phonological L*H% melody, consisting of a pitch accent on the stressed syllable and a H boundary tone. A second interpretation is that it realizes a phonological L%H* melody, consisting of a L boundary tone marking the initial position of a Prosodic Word and a pitch accent on the stressed syllable. The third option is that it realizes a L%H% melody, with L and H being boundary tones. In this scenario, intonation is not sensitive to word-level stress.

The three hypotheses make potentially different predictions about the interpretations of the F0 melody. For the first scenario (L*H%), the Penultimate hypothesis predicts that the L should always fall on the penult:

(18)   The Penultimate hypothesis on the L*H% melody
          L   H
          | |
          | |
          | |
        CψCψ

But the Sonority-Driven approach predicts that the L should appear on the ultima in [Cψ.Ca] words:

(19)   Sonority-Driven hypothesis on the L*H% melody

     L H   L H
     │ │   ＼ │
    CaCψ   vs.   CψCa
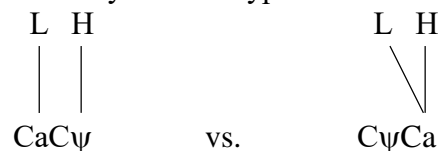
In this case, we would expect a greater slope over the final syllable of [Cψ.Ca] compared

with [Ca.Ca], [Ca.Cψ], or [Cψ.Cψ]. The effect on F0 would be a later transition to the H

target – i.e. a later rise in the [Cψ.Ca] case, with a rise in F0 over the final [a].

However, the intonation pattern in [Cψ.Ca] words shows no rise on the syllable

[Ca]. Instead, it is a level H on the [Ca] syllable. As shown in Figures 4.6 and 4.7, the pitch

contours of [Cψ.Ca] words overlap with the pitch contours of [Ca.Cψ] words in both

contexts. In other words, no F0 distinction is found to differentiate [Cψ.Ca] words from

[Ca.Cψ] words. Thus, no evidence favors the Sonority-Driven hypothesis.
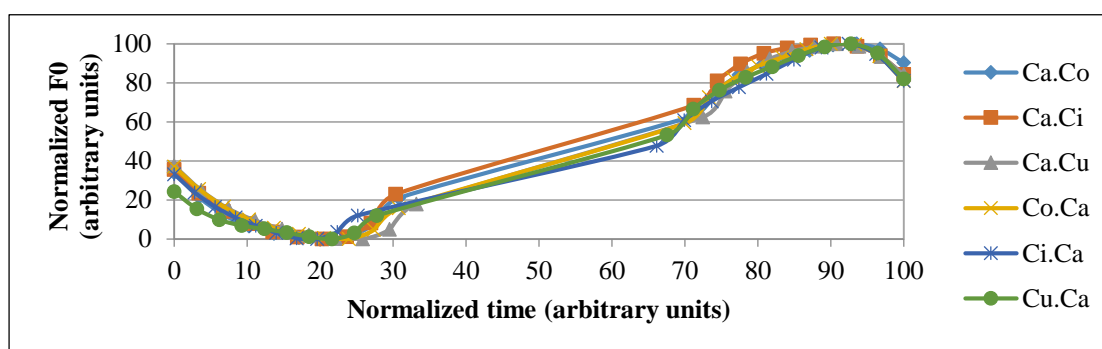
Figure 4.6: Intonation on [Ca.Cψ] and [Cψ.Ca] in the post-pausal context.
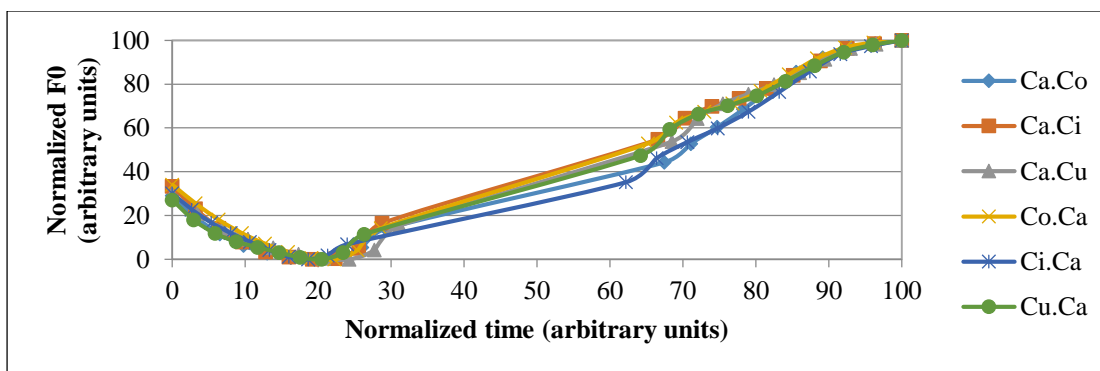
Figure 4.7: Intonation on [Ca.Cψ] and [Cψ.Ca] in the pre-pausal context.

For the second scenario (L%H*), the Penultimate hypothesis predicts that the H should always fall on the penult:

(20)   The Penultimate hypothesis on the L%H* melody

     L H

     CψCψ

On the other hand, the Sonority-Driven approach predicts that the H should appear on the ultima in [Cψ.Ca] words:

(21)   Sonority-Driven hypothesis on the L%H* melody

     L H   L H

     CaCψ   vs.   CψCa
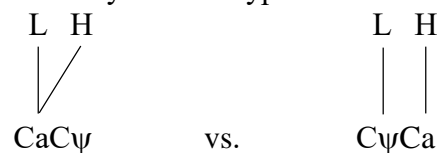
In this case, we would expect a greater slope over the first syllable of [Ca.Cψ], [Ca.Ca], and [Cψ.Cψ] compared with [Cψ.Ca]. The effect on F0 would be an earlier transition to the H target – i.e. an earlier rise in the cases of [Ca.Cψ], [Ca.Ca], and [Cψ.Cψ], with a rise in F0 over the first syllable.

As mentioned above, the pitch contours of [Ca.Cψ], [Ca.Ca], and [Cψ.Cψ] words overlap with the pitch contours of [Cψ.Ca] words in both contexts, as demonstrated in Figures 4.6 and 4.7. No F0 distinction is found to differentiate [Ca.Cψ] words from [Cψ.Ca] words. Thus, no evidence favors the Sonority-Driven hypothesis.

In short, assuming that one of the tones is a pitch accent, the intonation observed is only consistent with the Penultimate hypothesis, not the Sonority-Driven hypothesis. If neither tone is a pitch accent, then intonation is irrelevant to stress.

A final possible scenario would be that phonological conditions, such as a ban on tonal overcrowding, will force the L to always appear on the penult. In this case, we would expect stress to have the effect of lowering/raising F0 on the stressed vowel. So, in [Cψ.Ca], we would expect F0 on [$^\psi$a] to be higher/lower than on the final vowel in [Ca.Ca], [Ca.Cψ], or [Cψ.Cψ]. To test the possibility of tonal crowding, multiple comparisons of [$^\psi$a] vs. other vowels ([^{a}a, ^{a}ψ, $^\psi$ψ]) were obtained by using a one-way ANOVA with a post-hoc Tukey HSD test.

The result for the post-pausal context is significant: $F(7,789)=4.5119$, $p<0.01$. However, a post-hoc Tukey HSD test shows that only two pairs, [$^\psi$a] vs. [^{i}i] and [$^\psi$a] vs. [^{u}u], are found to be statistically significant (for [$^\psi$a] vs. [^{i}i]: $p=0.0373$; for [$^\psi$a] vs. [^{u}u]: $p=0.0073$). Other pairs do not show any statistical differences, with all p-values greater than 0.3235. The result for the pre-pausal context is also significant: $F(7,773)=4.9156$, $p<0.01$. Three pairs, [$^\psi$a] vs. [^{i}i], [$^\psi$a] vs. [^{a}u], and [$^\psi$a] vs. [^{u}u], are found to be statistically significant (for [$^\psi$a] vs. [^{i}i]: $p=0.0039$; for [$^\psi$a] vs. [^{a}u]: $p=0.0104$; for [$^\psi$a] vs. [^{u}u]: $p=0.0071$). Other pairs do not show any statistical differences (all p-values greater than 0.4926), though the difference between [$^\psi$a] vs. [^{a}i] is marginal ($p=0.057$). If tonal crowding

exists in Gujarati, we would expect [$^\Psi$a] to differ from [^{a}a] in terms of F0. However, it does not, indicating that [$^\Psi$a] is actually unstressed if tonal crowding constrains the intonation contour in Gujarati. Notice that the high vowels [i, u] have higher F0 than the low vowel [a]. This is perhaps because high vowels such as [i] and [u] intrinsically have higher F0s than low vowels such as [a] (Whalen & Levitt 1995).

4.4.4 Duration

This section explores whether duration is an acoustic correlate of stress in Guajarati. Section 4.4.4.1 discusses vowel length in the pre-pausal sentence. Section 4.4.4.2 focuses on the post-pausal sentences. Section 4.4.4.3 discusses the perceptual robustness of vowel length.

4.4.4.1 Pre-pausal context

There was always a pause after the stimuli in the pre-pausal sentences, indicating that the stimuli are in the final position of a prosodic phrase. So, vowels in the ultimate syllable (e.g. [^{a}a] and [$^\Psi$a]) are expected to be lengthened.

For [a], [^{a}a] and [$^\Psi$a] are lengthened due to phrase-final lengthening, though the multiple comparisons of [a] show no significant difference, with all p-values greater than 0.0874. Based on the mean duration, all the ultimate [a]s become longer than penultimate [a]s, as shown in Figure 4.8.
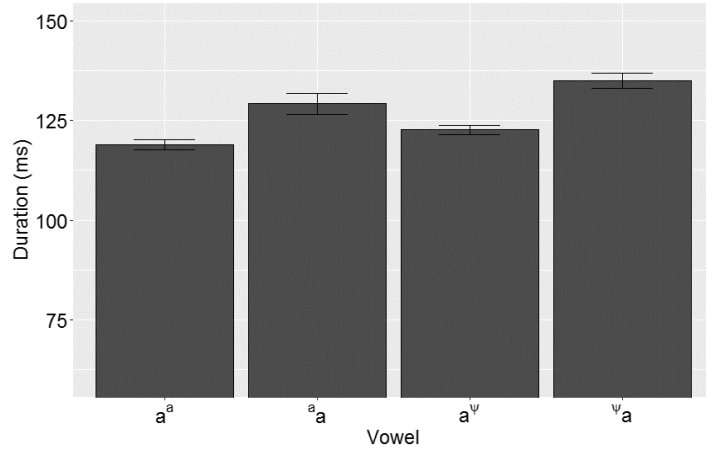
Figure 4.8: Durational differences between [a] vowels in the pre-pausal context. Error bars represent standard error of the mean.

Moreover, phrase-final lengthening is additive (e.g. Wightman *et al.* 1992, Gordon & Munro 2007). So, a phrase-final stressed vowel should still be longer than a phrase-final unstressed vowel. If this is the case, [ᵠa] should be longer than [ᵃa] if stress is sonority-driven in Gujarati. However, no significant difference was found between [ᵠa] and [ᵃa] (t=-1.443, p=0.4892). Thus, this finding further supports the Penultimate hypothesis.

The lengthening effect is found to be consistent for all vowels (for [o]: [oᵒ]: 112 (17) ms, [ᵒo]: 118 (29) ms, [oᵃ]: 103 (15) ms, [ᵃo]: 117 (31) ms; for [i]: 98 (20) ms, [ⁱi]: 115 (29) ms, [iᵃ]: 91 (16) ms, [ᵃi]: 113 (29) ms; for [u]: [uᵘ]: 94 (18) ms, [ᵘu]: 108 (24) ms, [uᵃ]: 94 (19) ms, [ᵃu]: 106 (25) ms), though the statistical analysis shows no significant difference, with all p-values greater than 0.1268. That is, all the ultimate vowels are lengthened so that they have longer duration than the penultimate vowels, based on mean duration.

Finally, vowel duration can be affected by many factors. Phrase-final lengthening is one of them. This effect obscures word-level stress by lengthening the duration of the final syllable. Therefore, it is important to disentangle word-level stress and phrase-level

influences.

4.4.4.2 Post-pausal context

It has been reported that in Gujarati stressed vowels are longer than unstressed vowels (Pandit 1958, Adenwala 1968, Lambert 1971, de Lacy 2006, Modi 2013). In particular, Lambert (1971) claims that [a] has a longer duration when it is stressed. So, under the Sonority-Driven hypothesis, it is expected that [$^\psi$a] in [Cψ.Ca] should have the same duration as [a^a] and [a$^\psi$] but a longer duration than [^{a}a] (putting aside the influence of word boundaries on duration). On the other hand, [$^\psi$a] is expected to have the same duration as [^{a}a] if stress falls on the penultimate syllable.
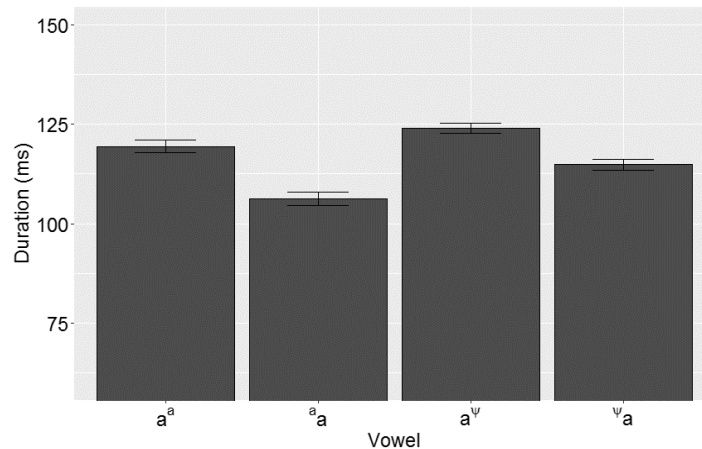
Figure 4.9: Durational differences between [a] vowels in the post-pausal context. Error bars represent standard error of the mean.

However, the comparison shows that [$^\psi$a] is not significantly longer than [^{a}a] (t=-2.210, p=0.1582). It should be noted that both [$^\psi$a] and [^{a}a] are in a prosodically similar position. As discussed in section 4.4.3, the target word has a rising (LH) contour, where the low tone falls on the penultimate syllable and high tone on the ultimate syllable. Intonation

might have an influence on the duration of the syllable; for example, Gandour (1997) reports that a vowel with a low tone is longer than that with a high tone in Thai. Since [ᵚa] and [ᵃa] are in the final syllable with a high tone, intonation should not influence duration.

Although the fact that [ᵚa] and [ᵃa] have the same duration is consistent with the Penultimate hypothesis, [ᵚa] is not significantly shorter than [aᵃ] or [aᵚ] (for [ᵚa] vs. [aᵃ]: t=1.103, p=0.6987; for [ᵚa] vs. [aᵚ]: t=2.27, p=0.1839). If duration is a cue of stress in Gujarati, the overall pattern is not predicted by either one of the hypotheses. Due to the fact that duration can be influenced by many other factors, both segmental and prosodic, I leave this issue for future investigation.

For other vowels, if stress is sonority-driven, [ψᵚ] is the only stressed syllable and thus should have longer duration than other vowels. However, [ψᵚ] does not differ from [ᵚψ], [ψᵃ], or [ᵃψ] in terms of duration (for [o]: [oᵒ]: 113 (17) ms, [ᵒo]: 95 (20) ms, [oᵃ]: 101 (17) ms, [ᵃo]: 103 (22) ms; for [i]: [iⁱ]: 98 (20) ms, [ⁱi]: 88 (24) ms, [iᵃ]: 89 (18) ms, [ᵃi]: 93 (19) ms; for [u]: [uᵘ]: 93 (21) ms, [ᵘu]: 90 (20) ms, [uᵃ]: 96 (20) ms, [ᵃu]: 87 (19) ms), with all p-values greater than 0.1755.

Cross-linguistically, duration has been shown to be an important acoustic correlate of stress (Fry 1955, Lieberman 1960, Everett 1998, Gordon 2004, Gordon & Applebaum 2010, among others). However, the statistical results above suggest that duration in Gujarati is not a robust cue of stress. The next subsection will focus on the perceptual robustness of duration in Gujarati.

4.4.4.3 Perceptual robustness

An important diagnostic is whether any consistent differences are perceptually robust. If

differences are not perceptible, they cannot be learned directly, putting into question their relevance.

There are no perceptually significant differences between vowels in different positions in terms of duration. Adopting Klatt (1976: 1219)'s Just-Noticeable-Difference (JND) for segmental duration of 20%, the perceptually significant duration thresholds of [a] vowels in various positions can be calculated, as in Table 4.1.

Vowels	Raw Duration (ms)	20% Threshold (ms)
[aᵃ]	119	23.8
[ᵃa]	106	21.2
[aᵠ]	124	24.8
[ᵠa]	115	23

Table 4.1: Raw duration of [a] and the 20% threshold.

The average of the threshold is 23.2 milliseconds. Clearly, the durational differences of [a] do not cross this threshold compared to each other. The pair which shows the greatest durational difference is [ᵃa] vs. [aᵠ] (18 milliseconds), which is still 5 milliseconds less than the averaged threshold. The durational differences of other pairs are far lower than the threshold. Moreover, the raw durational difference between each vowel is roughly 9.7 milliseconds on average. The averaged durational difference does not cross the averaged threshold, either. Based on these findings, I conclude that duration is not a reliable perceptual cue of stress in Gujarati.

4.5 Implications

This section discusses the implications of the study reported in the preceding sections. Section 4.5.1 identifies analytical implications for theories such as Optimality Theory

while section 4.5.2 offers possible explanations for incorrect interpretations of stress in Gujarati.

4.5.1 Symmetric effect

Gujarati is important for sonority-driven stress because it is one of very few cases where stress treats certain peripheral vowels differently from other peripheral vowels (see chapter 5). Most other cases of sonority-driven stress involve avoidance of schwa, which can be analyzed in a variety of different ways (see chapter 3 and 5).

de Lacy (2002, 2004, 2006) proposes that there is a unifying theoretical mechanism that accounts for sonority-driven stress and this same mechanism accounts for interactions at all prosodic levels. Following his work, the sonority hierarchy in (3) can be expressed through the form of constraints in Optimality Theory. The symmetric constraint forms and definitions are given schematically in (22). The category foot head (HD) refers to the stressed syllable of a foot while the category foot non-head (NON-HD) refers to the unstressed syllable of a foot.

(22)   Sonority constraints *(NON-)HD$_\alpha$/β

    a. *HD$_\alpha$≤β

      Assign a violation for every segment in Hd$_\alpha$ that is lower than or equal to β on scale F.

    b. *NON-HD$_\alpha$≥β

      Assign a violation for every segment in non-Hd$_\alpha$ that is greater than or equal to β on scale F.

In general, *HD$_\alpha\leq\beta$ and *NON-HD$_\alpha\geq\beta$ have the ability to restrict certain vowels of different sonority in head and non-head positions. The constraint *HD$_\alpha\leq\beta$ plays an essential role in sonority-driven systems since it can ban vowels with low sonority in head position. In particular, *HDFt≤{e,o} plays a crucial role in Gujarati stress since it is the foot head which requires high sonorous vowels (de Lacy 2002: 74-5), as shown in (23). Some constraints and their ranking are omitted in the tableau below. That is, FT-BIN dominates ALL-FT-R, and TROCHEE is undominated.

(23)   *HDFt≤{e,o} » FT-BIN

/hɛɾan/	*HDFt≤{e,o}	FT-BIN
☞a. hɛ(ɾán)		*
b. (hɛ́ɾan)	*!	

The key is that the non-metrical constraint *HDFt≤{e,o} must outrank the metrical constraint FT-BIN in order for candidate (23a) to be optimal. Candidate (23b) is ruled out because the head contains an [ɛ]. The competitor (hɛɾán), with an iambic foot, is eliminated through the undominated constraint TROCHEE. The metrical structure is changed due to the fact that *HDFt≤{e,o} outranks FT-BIN. However, *HDFt/v cannot exist if there is no sonority-driven stress.

Similarly, *NON-HDFt/v cannot exist because it can be used to generate the Gujarati system, as demonstrated in (24).

(24)   *Non-HDFt≥{a} » Ft-Bin

/hɛɹan/	*Non-HDFt≥{a}	Ft-Bin
☞a. hɛ(ɹán)		*
b. (hɛ́ɹan)	*!	

However, *(Non-)HDα/β is necessary to account for stress-driven neutralization, deletion, metathesis, and coalescence (de Lacy 2006: ch.7). These are cases where prosodic structure is kept constant and sonority changes. Take stress-driven deletion as an example. The constraint *Non-HDFt≥{a} says [a] is not allowed in non-head position. So, deleting [a] in non-head position can avoid the violation of *Non-HDFt≥{a}. This is evident in Lushootseed (Urbanczyk 1996, Gouskova 2003). The low vowel [a] is deleted if it would appear in the non-head of a foot.

(25)   Lushootseed [a]-deletion in the non-head of a foot

/RED-caq'/   [(ˈcacq')]   'to spear big game on salt water', *[(ˈcacaq')]

/RED-walis/   [(ˈwawlis)]   'little frog', *[(ˈwawa)lis]

/RED-laq-il/   [(ˈlaʔlqil)]   'be a little late', *[(ˈlaʔla)qil]

This pattern can be explained by *Non-HDFt≥{a} outranking the anti-deletion constraint Max (de Lacy 2007), as shown in (26). The constraints All-Ft-L and Ident[low] must also dominate Max. Candidate (26d) is the winning candidate because it avoids [a] in non-head position by deleting the [a].

(26)   Right-aligned trochees

/RED-walis/	*NON-HD$_{Ft}\geq$\{a\}	ALL-FT-L	IDENT[low]	MAX
a. (wáwa)lis	*!			
b. wawa(lís)		*!*		
c. (wáwə)lis			*!	
☞d. (wáwlis)				*

If there is no sonority-driven stress, the existence of *HD$_{\alpha}\leq\beta$ and *NON-HD$_{\alpha}\geq\beta$ is problematic.

The repair strategies for the constraint *(NON-)HD$_{\alpha}/\beta$ could be either to fix the prosody or change the vowel sonority. As a consequence, we lose the ability to account for stress-driven phenomena other than sonority-driven stress, such as neutralization, deletion, metathesis, and coalescence.

The fundamental problem is one of 'too many solutions' (e.g. Blumenfeld 2006). While the *(NON-)HD$_{\alpha}/\beta$ constraints can motivate vowel reduction and deletion, they should not be permitted to motivate relocation of metrical heads. It is not the goal of this chapter to propose a solution to the 'too many solutions' problem. Instead, the goal is to identify sonority-driven stress as a potential case in need of a solution.

4.5.2 Perceptual implications

A significant question remains unanswered in this study: Why did the previous investigators perceive Gujarati stress as sonority-driven? Section 4.2.2 shows that while the majority of the descriptions agrees that there is some sonority-driven stress, none of them agree on the details. In addition, no phonological or morpho-phonological processes refer to stress except for allophony. Stress is also not contrastive in Gujarati.

The diversity of descriptions suggests the possibility that previous investigators

were profoundly influenced, and misled, by their native perceptual systems in detecting the location of stress in Gujarati (See e.g. Bowern *et al*. in preparation). This is a reasonable speculation since most of the investigators who report Gujarati to have sonority-driven stress were non-native speakers (e.g. Cardona 1965, de Lacy 2002).[6] In his study of Chuvash stress, Dobrovolsky (1999) proposes that non-native listeners can rely on acoustic cues that are significant in their native language, even when those cues are not used to realize stress in the target language. For example, if listeners are attuned to large durational differences to determine stress position, Gujarati will provide little in terms of consistent value. Instead, however, listeners' intent on using duration to identify stress might turn to inherent vowel duration.

It so happens that penultimate [a] is inherently the longest vowel, followed by final [a], and these are longer than the other vowels in a significant way. The average duration of all the vowels pooled from the post-pausal sentence is listed here: vowels in the penult: [a]: 122 ms, [o]: 107 ms, [i]: 92 ms, [u]: 94 ms, vowels in ultima: [a]: 111 ms, [o]: 99 ms, [i]: 90 ms, [u]: 88 ms. As can be seen, /a/, either in penult or ultima position, has the longest duration among the four vowels in Gujarati. Comparing the ultimate [a] with the penultimate [o, i, u] shows that even the unstressed ultimate [a] has a longer duration than the stressed [i] and [u]. A one-way ANOVA analysis with four independent treatments shows that the comparison is significant: $F(3,795)=45.346$, $p<0.01$. A post-hoc Tukey HSD test shows that the ultimate [a] has significantly longer duration than the penultimate [i]

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[6] Mistry (1997), Suthar (as in Cardona & Suthar 2003), and Modi (2013) might be native speakers of Gujarati. However, even the native speakers' descriptions disagreed. It is possible that the authors were influenced by previous desciptions, except for Modi (2013). Modi (2013) is the only one to treat all the peripheral vowels as a category distinct from schwa. Stress in Gujarati might be fundamentally unimportant to native speakers in terms of perception and processing, given the lack of morpho-phonological processes that refer to it, and its irrelevance in marking lexical distinctions.

and [u] (for [a] vs. [i], p<0.01, for [a] vs. [u], p<0.01). The difference between [a] and [o] is not significant (p=0.081).[7]

As a consequence, a perceptual system attuned to durational differences could interpret inherent vowel duration differences as phonologically-controlled. This speculation might correspond to Masica (1991: 121)'s assertion about Gujarati stress: "Those [formulations of stress assignment] by foreigners sometimes confuse the prominence of long vowels with stress".

Similar findings are reported by Dobrovolsky (1999) for Chuvash, and by Bowern *et al.* (in preparation) for Yidiny.

According to Krueger (1961), stress in Chuvash falls on the rightmost heavy syllable (a syllable containing a vowel other than schwa), otherwise on the initial syllable. However, Dobrovolsky (1999) argues that there is no default initial stress in Chuvash. Dobrovolsky measured peak intensity, average intensity, duration, fundamental frequency, and the intensity integral of disyllabic words with the following combinations: HH, HL, LH, and LL (H=heavy syllable, L=light syllable). The results show that the first L in LL is not realized by greater peak, average, and total intensity, nor by increased duration. Instead, the first L has the highest fundamental frequency, which subsequently falls throughout the rest of the word. This initial peak in fundamental frequency is a consistent property of the initial syllable, even when it was not predicted to be stressed. Therefore, what is perceived as a default stress is actually a falling intonation that is assigned at a higher suprasegmental level than word-level stress assignment.

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[7] The fact that the durational difference between [a] and [o] is not significant might account for Adenwala (1965)'s claim that stress is attracted to all non-high peripheral vowels ([a, ɛ, ɔ, e, o]). If so, then the perceptual account plausibly accommodates Adenwala's description.

On the other hand, Dixon (1977a, b) claims that stress in Yidiny is by default trochaic with left-to-right alignment. In addition, stress is attracted to long vowels, as in [durgúː] 'mopoke owl (absolutive)'. However, Bowern *et al*. (In prep) argue that Yidiny stress is consistently word-initial, and does not move to long vowels. Of the four types of phonetic evidence examined, including duration, intensity, pitch, and centralization, duration and pitch provide clear evidence for consistent initial stress. To be specific, stress appears consistently on the initial syllable of the word, and it is realized primarily by increased duration and a L*+H pitch accent. Bowern *et al*. further provide possible explanations to account for Dixon's impression on Yidiny stress. One of the possible confusions is that, in Yidiny, phonologically long vowels are on average 1.7 times the length of their short counterparts. This corresponds to Oller (1973)'s finding in English that stressed vowels are on average 1.5 times the length of unstressed vowels. Due to the similar duration ratio between the duration of stressed and unstressed vowels, Dixon might misperceive the phonologically long vowels as stressed based on his own perceptual system.

Bowern *et al*. (in preparation)'s conjecture corresponds to Fry (1955)'s findings for English. Fry performs a perception study to test whether English speakers use duration and intensity as correlates of stress. He discovers that when the vowel is long and of high intensity, listeners agree that the vowel is strongly stressed. When the vowel is short and of low intensity, it is judged as weakly stressed. In particular, duration ratio is a more effective cue than intensity ratio. The whole range of intensity change produces an increase in the number of judgments of only 29% whilst the range of duration change increases the judgments by 70%. Thus, duration plays a crucial role for English speakers in their

detection of the location of stress.

Still another possibility is that the investigators confounded stress with the effects of phrase-final lengthening. As shown in section 4.4.4.1, the stimuli vowels are significantly lengthened in the pre-pausal sentence environment. It is conceivable that investigators listen to the words in phrasal-final position and identify the lengthened final [a] as stressed. Moreover, words in citation forms are simultaneously phrase final. The words elicited in previous studies are perhaps uttered in isolation. So, words with the shape [Cψ.Ca] are reported as having final stress because [ᵂa] is lengthened, even though the lengthening is not the realization of phonological metrical structure.

4.6 Conclusion

This chapter has shown that there is no evidence for sonority-driven stress in Gujarati. Specifically, there is no evidence that stress seeks out [a], avoiding less sonorous vowels. The evidence instead supports consistent penultimate stress.

This finding is important because Gujarati has been central evidence for the claim that sonority-driven stress exists (de Lacy 2002, 2006). Gujarati is the most extensively documented case of sonority-driven stress, and one of the few cases where stress is claimed to make a distinction between peripheral vowels. Without Gujarati as evidence, the claim that there is sonority-driven stress is far more uncertain.

CHAPTER 5

TYPOLOGY

5.1 Introduction

This chapter discusses the languages that have been claimed to exhibit sonority-driven stress, and how the present theory relates to them. The point of doing so is not to provide evidence for the theory. As previous chapters have shown, relying on grammatical descriptions for stress evidence presents analytical and interpretive challenges; a thorough-going typology would require careful acoustic and phonological analyses of all putative cases. For instance, I have shown by analyzing Gujarati and Piuma Paiwan that determining whether there is sonority-driven stress is difficult, and impressionistic descriptions tend to be unreliable and imprecise. I have also shown that even when impressionistic descriptions are supported by acoustic evidence (e.g. Piuma Paiwan), they are not necessarily correct in the details, and those details can have profound consequences for theoretical analysis and implications.

So, the goal of this chapter is not to present impressionistic descriptions of other languages as *evidence* for my theory. Instead, the first goal is to evaluate likely places to look given existing grammatical descriptions, and what to look for, how to look for it, and how to interpret results of future careful phonetic and phonological work. Accordingly, section 5.2 discusses languages reported to have stress systems that are sensitive to distinctions among peripheral vowels, while section 5.3 examines languages reported to have stress systems that are sensitive to central vowels (i.e. 'schwa').

The second goal is theoretical: to identify the sonority-sensitive metrical systems the present theory predicts *could* be generated by the phonological module. Accordingly, section 5.4 presents a factorial typology with a select set of relevant constraints, and identifies significant types of sonority-sensitive metrical systems.

5.2 Peripheral vowel distinctions

The present theory claims that sonority-driven stress cannot be sensitive to peripheral vowel distinctions. This section starts by examining the 14 languages known to me that are reported to have such peripheral vowel stress sensitivity. For each language, I list the references found in the literature, and report the default stress position and its sonority hierarchy. In section 5.2.2, the present theory is reviewed. The remaining sections discuss phonological evidence for the cases, the problem of inaccurate description due to impressionistic methods, the challenges of acoustic evidence in stress evaluation, and artificial language learning.

5.2.1 Sources

Of the 14 languages, six were described by single sources: Yessan-Masyo, Ma Manda, Pichis Asheninca, Nanti, Yimas, and Cowichan. Of the other eight languages, seven have multiple descriptions by different authors: Gujarati, Mordwin, Kara, Nganasan, Kobon, Harar Omoro, and Umutina. For the remaining one, Takia, there are multiple descriptions by the same author.

Disagreements about stress assignment were found in four out of the seven languages with multiple descriptions: i.e. for Gujarati, Kara, Nganasan, and Kobon.

Gujarati is the most extensively described case with peripheral vowel distinctions; detailed discussion of the disagreements among sources is provided in chapter 4, where it is also shown that stress in Gujarati regularly falls on the penultimate syllable, instead of being attracted to [a] (see chapter 4).

For Nganasan, de Lacy (2002, 2004) claims that low and mid vowels are conflated for stress purposes, as are high vowels with central vowels; the resulting sonority sensitivity for stress is | a, e, o > i, u, ə, ɨ |. However, Vaysman (2009) reports that stress is not sensitive to peripheral distinctions, but avoids central vowels.

For Kara, the sole difference between sources is in the transcription of central vowels. Schlie & Schlie (1993) transcribes the central vowel as [ə], whereas Schlie (1996) transcribes the central vowel as [ɐ]. Nonetheless, both descriptions agree that [a] attracts stress away from the default position.

For Kobon, Davies (1980) says that stress normally falls on penultimate syllables, but Davies (1981) claims that there is a three-way distinction between low vowels (also including diphthongs), mid and high vowels, and central vowels.

The descriptions are summarized in Table 5.5.1 below. Table 5.1 lists the conflicting descriptions mentioned above. To explain the form of the table, each description was examined and the default stress position and sonority categories for stress were identified. For example, Ross (2009: 762) reports that the default stress position in Takia is the final syllable, as in [tamán] 'her/his father'. However, stress occurs on the rightmost or only [a] in the word, as in [nánun] 'her/his child' and [ŋásol] 'I fled'. If there is no [a], stress occurs on the last or only [e] or [o], as in [krŋén] 'his/her finger/toe', [usól]

'you (SG) fled', [péin] 'woman'. Based on the description prodivided by Ross, the sonority

distinctions that stress is sensitive to in Takia are therefore | a > e o > i u |.

Language	*Version*	*Default Stress Position*	*Sonority distinctions for stress*
Yessan-Mayo (Uto-Aztecan)	Foreman & Marten (1973)	CV́CVCV	a > ɔ, ʌ , ɨ
Ma Manda (Finisterre-Huon)	Pennington (2013)	CV́CVCV̀	a > e o > ə > i u > ɨ
Pichis Asheninca (Arawakan)	Payne (1990)	CVCV́CV	a e o > i
Gujarati (Indo-Aryan)	See chapter 4	See chapter 4	See chapter 4
Mordwin (Finno-Ugric)	Tsygankin & Debaev (1975) Kenstowicz (1997)	CV́CVCV	e o ä a > i u ɨ
Nanti (Arawakan)	Crowhurst & Michael (2005)	CVCV́CV	a > e o > i
Kara (Austronesian)	(a) Schlie & Schlie (1993)	CV́CVCV	a > ɛ ɔ e o ɪ ʊ i u ə
	(b) Schlie (1996)	CV́CVCV	a > ɛ ɔ e o ɪ ʊ i u ɐ
Nganasan (Uralic)	(a) de Lacy (2002, 2004)	CVCV́CV	a e o > i y u ə ɨ
	(b) Vaysman (2009)	CVCV́CV	a e o i y u > ɨ > ə
Takia (Austronesian)	Ross (1995, 2002, 2003, 2009)	CVCVCV́	a > e o > i u
Yimas (Lower Sepik)	Foley (1991)	CV́CVCV	a > i u > ɨ
Kobon (New Guinea)	(a) Davies (1981)	CVCV́CV	a au ai > o e u i > ə ɨ
	(b) Kenstowicz (1997)	CVCV́CV	a > e o > i u > ə > ɨ (based on data from Davies (1981))
	(c) Davies (1980)	CVCV́CV	Penultimate stress
Harar Omoro (Uto-Aztecan)	Owens (1985) de Lacy (2002)	CV́CVCV	a > ʌ, ɔ, ɨ
Umutina (Macro-Jê)	Telles (1995), Wetzels & Meira (2010), Wetzels, Telles & Hermans (2014)	CVCVCV́	a > ɛ ɔ e o > i u ɨ (based on data from Wetzels, Telles & Hermans (2014)) *or* a > ɛ ɔ > e o > i u ɨ
Cowichan (Salish)	Bianco (1998)	CV́CVCV	a e > i > ə

Table 5.1: Languages with peripheral vowel distinctions.

5.2.2 Theory

The theory proposed here claims that no stress system can be sensitive to peripheral vowel distinctions. In other words, the theory does not have a constraint C such that C is a markedness (i.e. output) constraint that favors a higher sonority vowel over a stressed lower sonority one in a specific metrically-defined position (cf. Kenstowicz 1997, de Lacy 2002, 2004, 2006).

An example of such a constraint is *HD$_{Ft}$≤{e,o}, which penalizes vowels that have the sonority of a mid peripheral vowel or smaller (e.g. [e o i u]) in the head position of a foot (de Lacy 2002 et seq.). Similarly, *NON-HD$_{Ft}$≥{a} is violated when a very high sonority vowel appears in the non-head syllable of a foot. The action of such constraints is illustrated in the tableaux below.

(1)　Constraint on head sonority

/paki/	*HD$_{Ft}$≤{e,o}	ALIGN-HD-R
☞　a. (páki)		*
b. (pakí)	*!	

(2)　Constraint on non-head sonority

/paki/	*NON-HD$_{Ft}$≥{a}	ALIGN-HD-R
☞　a. (páki)		*
b. (pakí)	*!	

In (1), the constraint penalizes a lower sonority vowel in head position, so candidate (1b) is ruled out. In (2), the constraint penalizes a higher sonority vowel in non-head position, so candidate (2a) is eliminated. However, my theory predicts that such constraints cannot exist.

Note that it is possible to have an 'apparent' sonority-driven stress system. Such a system could exist if the higher sonority vowels all had some incidental feature that the lower sonority vowels did not. For example, suppose the language has a disjoint short-long vowel inventory, where short vowels are [i u e o] and the only long vowel is [aː]. In this case, stress may be attracted to the low vowel. However, the present theory claims that such a pattern could only be due to [aː]'s greater moraic content, not to its low sonority.

If non-moraic mid and low vowels indeed exist, it is then possible to generate apparent sonority-driven stress systems with peripheral vowel distinctions. Suppose a language has a non-moraic mid vowel [^{e}] and a moraic low vowel [a]. Stress will avoid [^{e}] and fall on [a], as in [Cá.C^e] and [C^e.Cá]. However, stress assignment in such a system is due to the status of moraicity, rather than vowel sonority. Chapter 5 argues that such systems are not attested, suggesting that non-moraic mid and low vowels do not exist, or cannot behave in a way that produces sonority-driven stress.

In principle, it should be fairly straightforward to prove that 'peripheral' stress systems exist. A phonological approach would demonstrate that metrical heads are attracted to high sonority vowels in the presence of lower sonority vowels in the default metrical head position. Relevant evidence would involve phonological processes that provide clear evidence for metrical structure, such as vowel reduction, fortition (e.g. stress-conditioned aspiration), or morpho-phonological processes that involve affixation to metrical heads (e.g. American English expletive infixation).

A phonetic approach would involve showing that lower sonority vowels have acoustic/articulatory characteristics of stressed syllables in just those cases where the lower sonority vowels appear in a position that is not the default metrical head position.

There is one other potential type of sonority-driven stress system: the allophony-driven system. Blum (2018) argues that Munster Irish stress is typically initial, but falls on the peninitial syllable when the initial can be reduced to schwa while the peninitial cannot. For example, in /badax/, /a/ is prevented from reducing to schwa by the following /x/, and so the first vowel reduces instead: i.e. [bə.dáx], *[bá.dax], *[bá.dəx]. Blum (2018) argues that stress in this system is driven by the need to reduce vowels. So, [bə.dáx] has peninitial stress *so that* the initial vowel might reduce; its competitor *[bá.dax] (with default initial stress) is ruled out because it has more full vowels than [bə.dáx], and the competitor *[bá.dəx] is eliminated because it reduces a vowel that is blocked from reduction. A relevant tableau is shown below, where REDUCE requires non-head vowels to become schwa, and *əx blocks reduction before [x]:

(3)   Stress in Munster Irish

/badax/	*əx	REDUCE	ALIGN-HD-L
☞ a. bə.dáx			*
b. bá.dəx	*!		
c. bá.dax		*!	
d. ba.dáx		*!	*

Superficially, allophony-driven stress can appear to be a sonority-driven stress system, depending on the details. In the Munster Irish case, /a/ is unreducible before [x], so its stress system can be described as "Stress the leftmost syllable unless both (a) the peninitial contains [ax] and (b) the initial does not contain [ax] or a long vowel." Such a description suggests that stress is attracted to [ax] – a kind of sonority-driven stress system (though a rather curious one, as [a] is crucially accompanied by [x]).

However, there are tell-tale signs that allophony-driven stress systems are not driven by a need for metrical heads to have high-sonority vowels. Specifically, the conditions on stress placement refer to specific contexts that block reduction. In the case of Munster Irish, this is the pre-[x] context. As only Munster Irish has been shown to have an allophony-driven stress system, the reader is referred to Blum (2018) for details.

5.2.3 Phonological evidence

Since the present theory claims that peripheral languages cannot exist, the theory implies that all the languages listed in Table 5.5.1 are either inaccurately described or misanalysed. This section comments on the phonological evidence presented for stress in the cases listed above, and its robustness as evidence for peripheral stress.

There are many potential types of phonological evidence for metrical head positions: e.g. contrast preservation (Beckman 1998), vowel reduction (Crosswhite 1999, de Lacy 2007), allophony, fortition (Bye & de Lacy 2008), and tone attraction (Downing 1990).

In my survey, there are four languages where the descriptions report phonological evidence for stress position: Ma Manda, Gujarati, Nganasan, and Takia. I summarize the phonological evidence reported for each language below.

• *Ma Manda: allophony*

Pennington (2013: 1) mentions that "/i/ and /u/ tend to be reduced to [ɨ] in unstressed environments". The vowel reduction to [ɨ] is an approximation, as the actual quality varies from high to central. Specifically, Pennington (2013: 61) notes that "The high peripheral

vowels /i u/ occur in all environments. They are particularly susceptible to reduction to a more central location, in varying degrees, in unstressed environments (e.g., /u/ → [ʊ ɯ ɨ])."

However, this vowel reduction is not solely sensitive to stress assignment. Pennington (2013: 99) (hereafter 'P') observes that "First of all, full high vowels are rare in words of three syllables or more. In words of this length, the high vowels (even when stressed) are reduced." P then makes a generalization that the greater the number of syllables in a word, the more likely that the high vowels will be pronounced from a centralized location. So, vowel reduction is also conditioned by word length. P gives two examples showing vowel reduction in a trisyllabic word: [ní.min] 'cousin' and [nɪ̀.mɨ.nə́] 'cousin-1SG.POSS'. After the attachment of the suffix /ə/, the first and the second vowels reduce to [ɨ], with the first one receiving secondary stress. Note that even the unstressed vowel in [ní.min] 'cousin' does not undergo reduction in P's transcription.

Moreover, vowel reduction in unstressed syllables is optional. P (p. 100) notes that "High vowels are also reduced in words with fewer than three syllables. This occurs primarily in unstressed syllables, as shown in [sɨ.bə́t] ~ [si.bə́t] 'food' and [qá.biŋ] ~ [qá.buŋ] 'smell'." The data suggests that there is free variation between [i u] and [ɨ]. Thus, unstressed high vowels have a propensity for reduction.

In short, the exact conditions on vowel reduction in Ma Manda, and its optional nature, mean that it is currently not particularly robust evidence for stress position. Given the description, there is a great deal of uncertainty: it is possible that reduction is not metrically sensitive.

The point in the above comments is not to assert that there is *no* phonological evidence for sonority-driven stress in Ma Manda. Instead, I merely emphasize that the

evidence is not clear or straightforward. The present theory predicts that close analysis would reveal that vowel reduction is not conditioned in a way that supports sonority-driven stress placement.

• *Gujarati: allophony*

Several descriptions mention stress-conditioned allophony in Gujarati: i.e. the central vowel [ə] is realized as [ʌ] when it is stressed (Patel & Mody 1960, Lambert 1971, Nair 1979). Moreover, allophonic alternations between high peripheral and non-peripheral vowels [í ú]~[ɪ ʊ] are reported to be conditioned by stress (Cardona 1965, de Lacy 2002): the non-peripheral allophones appear in non-final open syllables, except when they are stressed.

However, this description is not supported by the phonetic analysis in chapter 4: vowel quality is shown to not vary due to stress. In general terms, this finding suggests that impressionistic descriptions of allophony – particularly when involving fine acoustic distinctions – may also be unreliable, and therefore do not provide clear evidence for stress.

Certainly, the distinction between [ə] and [ʌ] is potentially quite slight, involving only a difference in F2. In fact, if 'ə' means 'a vowel that is highly influenced by its environment', then the difference between 'ə' and 'ʌ' is mainly one of variation – i.e. 'ʌ' has a smaller F2 variability (i.e. possibly standard variation) than 'ə'. However, that is an observation that can only be made reliably through multiple measurements and comparison of different environments in a controlled study; impressionistic methods are unlikely to provide the kind of precision necessary for such an assertion.

• *Takia: allophony*

Ross (2002) mentions that "[a]n unstressed vowel may be realized as [ə]", giving examples

of 's/he hit you' as "[ˌi.fə.ˈno]~[ˌi.fu.ˈno]~[ˌif.ˈno]".[1]

    In all of the cases cited, Ross proposes that the schwa vowel is actually epenthetic:

i.e. /i-fn-o/. Is schwa allophony then evidence of stress, or evidence of some other process?

In the case of /i-fn-o/, for example, Ross presents three forms, as above. The difference

between the forms is essentially in the duration of the medial vowel: a standard vowel [u]

vs. a brief [ə] vs. no duration at all. It is possible, then, that the distinction is really one of

moraicity, i.e. one mora vs. no moras vs. outright deletion. Therefore, the question is

whether schwa realization is actually conditioned by lack of moraicity, and then whether

lack of moraicity is conditioned by stress. Given that the examples all involve medial

vowels reducing or deleting, it is possible that the conditioning environment is really one

of mora elimination, i.e. /i-fun-o/ → [i.fᵊ.no], in order to epenthesize a moraically minimal

vowel.

    The point here is that there is a complex relationship between stress, reduction, and

deletion that requires careful phonetic analysis. A close phonetic analysis would reveal the

extent of deletion, and the status of reduction as either resulting in a moraic or non-moraic

vowel. Without such information, it is difficult to assert exactly what the reported vowel

reduction/deletion means for stress position here. Regardless, Takia promises to be an

interesting case to analyze phonetically.

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[1] The latter is transcribed in Ross (2002) as [ˌif.no] – it is corrected here by adding a primary stress mark.

● *Takia: harmony*

Ross (1995) describes a vowel harmony process where the vowel of the stressed syllable

determines the vowel quality of the preceding syllable. If the vowel of the stressed syllable

is [e] or [i], the preceding vowel is [i]. If the vowel of the stressed syllable is [o] or [u],

then the preceding vowel is [u]. For example, /i-funi-da/ → [ifinída] 'he is hitting (it)'.

Thus, vowel harmony in Takia might provide crucial evidence for stress.

However, Ross (2002) claims that the relationship between the trigger vowel and

stress is irrelevant. Ross (2002) divides each word into two parts. Part B comprises the

tonic and post-tonic syllables. However, if the tonic syllable is onsetless, part B includes

the pre-tonic syllable. Part A is all remaining syllables. The trigger vowel is the first vowel

other than /a/ encountered in part B. If the trigger vowel of part B is [u] or [o], then the

vowel in part A is [u]. If the trigger vowel of part B is [i] or [e], then the vowel in Part A

is [i]. Since the trigger vowel is the first vowel in part B, the trigger vowel is not always

the stressed vowel, as shown in (4). The trigger vowel is underlined here.

(4)   *Vowel harmony in Takia (data from Ross 2002: 219)*

        [kusál<u>o</u>m]   'spider'

        [tus<u>u</u>é]   'we poked (it)'

        [tig<u>i</u>ó]   'we called you'

[a] is transparent to round harmony, although it is stressed in [kusál<u>o</u>m]. As for the last two

examples, the stressed syllable is onsetless, so the previous syllable is included as part B.

Therefore, it is the unstressed vowel that determines the vowel quality of the preceding

syllable. It is possible that the syllabification is [ti.gio], and only vowels that are head moras initiate harmony.

The above data suggest a [round] harmony process. In other words, words are restricted such that vowel sequences such as *…{u/o}…{i/e} and *…{i/e}…{u/o} are not allowed. Ross (2002) further notes that if there is no trigger vowel, it is the first two consonants which determine the vowel quality in part A. Ross does not provide any rules in his description.

There are other generalizations about parts A and B. As A and B are defined with reference to stress, these generalizations are stress-conditioned, and so are potential phonological evidence for stress.

First, part A cannot contain a mid vowel [e o]. In purely phonotactic terms, this generalization can be expressed as: (a) *…{e,o}…{a}, (b) *…{e,o}…{e,o}, and (c) *…{e,o}…{i,u}. In other words, a mid vowel can only occur in a word if followed by a high vowel. It is possible that the limited distribution of mid vowels is not related to stress, but rather due to harmony and disharmony restrictions.

Second, [i] generally does not co-occur with [u]. Similarly, this suggests a parasitic harmony, with [round] parasitic on [+high].

It is far from clear, then, whether stress has anything to do with the vowel distribution generalizations. Ross's own proposal is that there are epenthetic vowels, and their roundness and backness is determined by rightward spreading.

• *Nganasan: Consonant gradation*

Vaysman (2009)'s and de Lacy (2002, 2004)'s stress descriptions disagree on the status of

high vowels [i, u, y]. Vaysman (2009: 25) notes that "[i]n de Lacy (2004, 2006)'s data, there are cases of stress shift from [u] and [i], but I have found no such shifts in the dialect of Nganasan with which I worked." In other words, there are no peripheral vowel distinctions, at least not consistently in all dialects: all vowels are conflated for stress purposes. Notably, de Lacy (2002, 2004) do not report any phonological processes that are sensitive to metrical structure. If Vaysman (2009) is right in her description, then Nganasan is not a case of sonority-driven stress with peripheral vowel distinctions.

Furthermore, Vaysman (2009) describes a consonant gradation process that is sensitive to metrical structure. However, she notes: "the foot structure that is marked by gradation **does not match** the stress pattern, namely the placement of the primary stress and its shifts from [ə] and [ɨ] leftwards" (p. 21; emphasis from the original). In other words, the evidence for metrical structure from phonological processes does not support the impressionistic claims about primary stress location. Consider the 2nd person dual suffix -*ti*/-*ði* in the following examples.

(5)   *Consonant gradation in Nganasan (data from Vaysman 2009: 45-46)*

   a. [(kó-ti)]   'your (du.) ear'

   b. [(bàku)(nú-ti)]   'your (du.) salmon'

   c. [(hahí)-(ði)]   'your (du.) wild deer'

   d. [(kə̀rï)(gəʎí)-(ði)]   'your (du.) march'

In Vaysman (2009)'s analysis, the 2nd person dual suffix is –ti when foot-internal, and –ði otherwise (a specific example of a more general consonant gradation process). This

analysis works only if trochaic feet are constructed from left to right.

However, the default primary stress falls on the penultimate syllable. This places the primary stressed syllable at odds with the trochaic foot parse needed for consonant gradation, as shown in (4a,b vs. c,d).

In other words, Nganasan presents phonological evidence that does not support the claims about primary-stress placement. It is possible that Nganasan has dual disjoint metrical tiers (e.g. Parker 1998) – regardless, at the very least consonant gradation provides no support for the claims about sonority-driven primary stress, and potentially contradicts it.

- *Summary*

In short, the phonological evidence for stress placement in 'peripheral' languages is slight. In one case, it either contradicts the stress claims or is irrelevant (Nganasan). In another, no acoustic evidence for the claimed allophony was found (Gujarati). In another, it is not clear whether the described harmony patterns require any reference to stress (Takia), or whether the allophony solely involves reduction of unstressed vowels (Takia and Ma Manda). The general point is that finding appropriate phonological or morpho-phonological evidence for stress is far from straightforward. Many descriptions require subsequent close acoustic analysis – impressionistic judgements seem to be unreliable or inadequately precise (see chapter 4).

5.2.4 Misdescription

In some cases, it is possible that other factors were overlooked in the description. For

example, Schlie & Schlie (1993) report that Kara has the vowels [a ɛ/e ɔ/o ɪ ʊ i u ə] and that stress falls on the rightmost [a], otherwise on the rightmost closed syllable, otherwise the stem-initial syllable.

However, Schlie (1996) present a different set of low vowels, including [ɑ] and [ɐ] instead of [a] and [ə]. Stress is described as being attracted to "syllables with the phoneme /ɑ/". From inspection of the data, it seems that [ɑ] occurs in diphthongs: xaot [xɑot] 'harvest', sait [sɑit] 'too, also', ngaul [ŋɑul] 'fish hook'. (It is also possible that [ɑ] appears as a monophthong only as a long vowel.) Unfortunately, Schlie (1996) only provides examples in orthography, not phonetic transcription. However, de Lacy (2007)'s description (which includes data from personal communication with the Schlies) seems to imply that stress seeks out long vowels and diphthongs (i.e. with [ɑ]). Certainly, all the examples with [ɐ] involve short vowels: e.g. avas 'to bark', pat 'dull', xawa 'rubbish'. In this case, the generalization seems to be that stress is attracted to long vowels, which happen to be [ɑː], and otherwise falls on closed syllables, else the stem-initial syllable. It just so happens that diphthongs and long vowels all involve [ɑ], so it only seems that stress seeks out [ɑ] whereas stress is really seeking out bimoraic nuclei.

Similarly, there are two competing descriptions for Kobon stress (from the same author). Davies (1981) claims that there is sonority-driven stress with peripheral vowel distinctions. On the other hand, Davies (1980) says stress normally falls on the penultimate syllable, with no information about vowel sonority. However, both descriptions concede that the analysis of stress is incomplete. Davies (1980: 58) mentions that "[t]he rules for the placement of stress cannot be stated comprehensively at this stage," and Davies (1981: 225) states that "[f]urther research is necessary before the rules for the placement of stress

can be stated comprehensively. The following remarks are made tentatively pending such further study."

Using data from Davies (1981), Kenstowicz (1997) proposes a slightly different sonority hierarchy. However, part of the hierarchy is made based on vowel in the default stress position. For example, Kenstowicz claims that [a] is more sonorous than [e] based on the data [ha.gá.pe] 'blood'. Word stress is restricted to one of the last two syllables, but the penult is the default position for stress. Therefore, it is not clear whether [a] is in fact more sonorous than [e].

Rasin (2016) compares the two hypotheses by re-organizing the data from both sources according to lexical category, morphosyntactic environment, and syllable structure. However, Rasin (2016) found that many words in the data have [a] as their penultimate vowel. These examples are usually unhelpful in distinguishing the two hypotheses. Among the approximately 550 words he collected, only 13 words clearly disambiguate the two hypotheses, with 7 examples supporting the sonority-driven hypothesis, and 6 examples supporting the penultimate hypothesis. Rasin (2016) concludes that there is no clear evidence for sonority-driven stress in Kobon.

5.2.5 Acoustics

The phonetic module can realize heads and non-heads in a variety of ways (e.g. Gordon & Roettger 2017, Roettger & Gordon 2017). Stressed vowels can be realized with an excursion in fundamental frequency (F0), increased intensity, and increased duration. Examples are found in diverse languages: e.g. English (Fry 1955, 1958), Polish (Jassem *et al*. 1968), Chickasaw (Gordon 2004), Turkish (Levi 2005), and Kabardian (Gordon &

Applebaum 2010). Other potential acoustic correlates of stress have come to light, such as vocalic peripheralization (or centralization of unstressed vowels) (Campbell & Beckman 1997, Gordon 2004), and lack of spectral tilt (Sluijter & van Heuven 1996).

In this section, I summarize the acoustic evidence reported for each language. Seven languages are found to report acoustic properties of stress in their descriptions, including Ma Manda, Pichis Asheninca, Gujarati, Nganasan, Takia, Yimas, and Kobon.

• *Ma Manda*

The description of the acoustics of stress provided by Pennington (2013) is worth citing in full, both for its relative extensiveness, and for its uncertainty:

"The accent system has been difficult to "pin down" due to a lack of convergence of the prototypical indicators of stress such as pitch, intensity, and duration … Stress is defined as "prominence", meaning that one syllable of each word is felt to be stronger than all of the others. This prominence is realized by a number of phonetic properties, including syllable duration, vowel quality, intensity, aspiration of voiceless plosives, and alignment with phrasal stress …

(20) Gradient properties of stressed syllables in Ma Manda
- lengthened vowel duration;
- vowel articulated close to its target value;
- syllable is pronounced with greater overall intensity;
- higher pitch than surrounding syllables;
- fortification or lengthening of onset consonants;
- increased aspiration of onset voiceless plosives;
- attracts phrasal stress.

…It is true, however, that there are often one or two primary cues to stress placement. Unfortunately, these properties seldom align with one another in Ma Manda. For instance, it is often the case that one syllable seems to be marked for primary stress in terms of pitch, while another seems marked for stress in terms of intensity. It does not seem to be the case that any indicator can be relied upon more than the others." (Pennington 2013: 80-82).

The description provides an insightful summary of the difficulty of using impressionistic methodologies: i.e. it is difficult to identify the acoustic correlates of stress without careful phonetic analysis, in part no doubt because humans have perceptual systems that are attuned to their native language, rather than the language they are describing. The uncertainty in Pennington (2013)'s description is illustrative, and suggests that Ma Manda is ripe for future close acoustic analysis.

- *Pichis Asheninca*

  "Stress in Pichis Asheninca is characterized by a combination of loudness or intensity, slight duration of the following consonant and sometimes higher pitch." (Payne 1990: 188).

The description of Pichis Asheninca stress given above is fairly typical of phonetic descriptions of stress in grammars or journal articles. It touches on intensity and F0, and adds duration of the following consonant. While these properties are fairly typical of stress, it is clear that close acoustic analysis would be necessary to determine what the realization of stress entails – i.e. just how slight the duration of the following consonant is, and what conditions F0 rise.

- *Gujarati*

Details of the phonetic descriptions of stress are provided in chapter 4.

- *Nanti*

  "Our transcriptions of word-level and foot-level stress are mainly based on the impressionistic judgments of the authors, especially of Lev Michael, who has done many years of fieldwork on Nanti and is a competent speaker. In addition, we have

confirmed our stress transcriptions by referring to spectrograms, where necessary." (Crowhurst & Michael 2005: 48).

The description of the acoustics of Nanti stress is interesting because it mentions an acoustic analysis (i.e. "spectrograms"). Unfortunately, the details of the acoustic analysis are not provided – e.g. what feature of the spectrograms was examined (spectral tilt, vowel quality). In fact, the acoustic qualities of stress are not mentioned. Such a description requires a great deal of trust on the part of the reader that impressionistic methods are reliable and precise enough for stress description. As the analyses of Gujarati and Piuma Paiwan have shown, there is good reason to question such assumptions.

- *Kara*

  "Primary stress is mainly a function of intensity but may work in combination with pitch. Secondary stress is usually a function of changing pitch. Under certain conditions primary and secondary stress appear to be equal. When this occurs both stressed syllables are marked with primary stress." (Schlie & Schlie 1993: 108-109).

  "Primary stress seems to be a function mainly of intensity, secondary stress of changing pitch." (Schlie 1996: 3).

The descriptions of Kara illustrate the uncertainty that can arise from impressionistic methods: "seems", "may", "usually", "under certain conditions ... appears". As the Gujarati and Piuma Paiwan analyses have shown, such uncertainty may reflect an awareness that the language's stress cues are not the same as the authors' native languages.

- *Nganasan*

  "Stressed vowels are realised with longer duration and loudness than unstressed vowels." (de Lacy 2004: 13).

"Correlates of stress in Nganasan are fundamental frequency, duration, and amplitude."
 (Vaysman 2009: 23).

These sources do not clarify whether descriptions of stress acoustics are based on impressionistic or machine-assisted measurements. However, de Lacy (personal communication) states that his description was impressionistic, based on listening to a native speaker. Given that Vaysman (2009) and de Lacy (2004)'s descriptions of stress differ, the reliability of impressionistic stress methodologies for Nganasan is in question.

- *Takia*

While there is no published information on the acoustics of primary stress, Ross (2002:218) comments on secondary stress: "Note, however, that this secondary stress is often hardly perceptible." (Ross 2002: 218). This statement is not particularly surprising given the difficulty of identifying acoustic effects of secondary stress.

- *Yimas*

 "Stress is marked phonetically by a higher pitch on the syllable and a somewhat
  lengthened vowel." (Foley 1991: 75).

See comments for Kobon below.

- *Kobon*

 "The nucleus of a stressed syllable is pronounced with greater intensity than the nucleus
  of an unstressed syllable, and sometimes with higher pitch." (Davies 1981: 225).

Crucially, almost all the descriptions are impressionistic, except for Vaysman (2009)'s description for Nganasan. Vaysman (2009: 27) states that schwa is very short: at a roughly constant rate of speech, schwa duration was c.25 ms, while short [a] was c.60 ms, and long [aa] c. 90 ms. However, it is not clear how vowel duration is affected by stress. Crowhurst & Michael (2005) mention that they confirm stress by referring to a spectrogram if necessary, though exactly what such reference entailed is not specified.

One theme in the descriptions is uncertainty. For example, Schlie (1996: 3) states that "[p]rimary stress seems to be a function mainly of intensity, secondary stress of changing pitch." It is not entirely clear whether intensity and F0 function as acoustic cues of stress in Kara. Some descriptions show that some acoustic cues can signal stress but they are less consistent. For example, Davies (1981: 225) states that the "nucleus of a stressed syllable is pronounced with greater intensity than the nucleus of an unstressed syllable, and sometimes with higher pitch." It is possible that the author's perception was influenced by intonation (e.g. Gordon 2014 – *the paper on intonation and stress*).

As detailed in the analyses of Gujarati and Piuma Paiwan, the problem with impressionistic descriptions is that the investigator's perception might be influenced by non-stress factors. Some phenomena potentially confound the perception of stress, such as domain-initial strengthening (e.g. Fougeron & Keating 1997), domain-final lengthening (e.g. Wightman *et al*. 1992), phrase-level intonation (Gordon 2014), surrounding segments (e.g. Peterson & Lehiste 1960, van Santen 1992), and intrinsic vowel differences (e.g. Peterson & Lehiste 1960, Whalen & Levitt 1995). For example, I suggest that intrinsic vowel differences might be behind the disagreements over Gujarati stress, where some investigators misperceived [a] as a stressed vowel because [a] is inherently longer than

other vowels (see chapter 4 for discussion). Note that only Crowhurst & Michael (2005) explicitly say that they avoid using words in citation form and phrase-final position.

In short, impressionistic descriptions of acoustic properties of stress appear to be unreliable and inadequately precise. The unreliability is clear in the cases where there are multiple independent descriptions of stress systems – there is typically widespread disagreement. The imprecision is clear in descriptions that emphasize their uncertainty.

• *Harar Oromo*

The final case discussed here is Harar Oromo. Owens (1985)'s describes the language as having a pitch accent or tone system. The analysis in de Lacy (2002) argues that the language has a metrical system to which tone is sensitive (i.e. high tone falls on the metrical head). So, there is no phonetic realization of stress; the identification of metrical structure is indirect, through tone placement.

5.2.6 Other evidence

A recent study by Carpenter (2006) suggests that stress assignment with peripheral vowel distinctions is learnable in artificial language learning. Carpenter investigates the role of Universal Grammar (UG) in the adult second language acquisition of phonological stress, examining whether universal linguistic phonological principles can be accessed by learners to aid them in acquiring the stress pattern of an artificial language. If second language learners have access to innate universal linguistic principles, they should be better able to learn the natural process over the unnatural one.

The 'natural' process for the vowel height experiment was: Stress the leftmost low vowel, else stress the leftmost vowel. Importantly, this system is similar to the one described for Gujarati by de Lacy (2004). The 'unnatural' process was the opposite: Stress the leftmost high vowel, else stress the leftmost vowel – i.e. an impossible system, according to de Lacy (2006) and others. The experiment was conducted with native speakers of American English and Quebec French. The results show that in terms of vowel height, both English and French speakers learned the natural rule better than the unnatural one.

Carpenter (2006)'s findings could suggest that there are innate phonological predispositions towards stressing higher sonority vowels. However, the results also showed that English and Quebec French speakers were able to learn the unnatural pattern fairly well. English speakers scored 70% correct in average on the natural pattern, and 58% correct in average on the unnatural pattern. For Quebec French speakers, they scored 58.3% correct in average on the natural pattern, and 53.7% correct in average on the unnatural pattern. In addition, as Carpenter (2006: 74) points out, learners' *prior experience* of the correlation between length and low vowels could lead them to prefer stressed low vowels over high vowels, even though the vowel durations were equalized in the experiments.

Carpenter (2006) also conducted experiments on syllable weight. The syllable weight experiments followed the natural/unnatural rules: Stress the leftmost heavy syllable, else leftmost, or, stress the leftmost light syllable, else leftmost. The results showed that neither English speakers nor French speakers learned the natural language better than the unnatural language, as there was no significant difference between the languages on the novel word scores.

I conclude that Carpenter (2006)'s findings do not provide clear evidence that there are innate predispositions for stress to seek out highly sonorous elements. While there is a slight difference in preference for a system where stress seeks out high sonority vowels vs. one where it seeks out low sonority vowels, it is not clear what the motivation for this preference is – it may not be due to phonological structures alone.

5.2.7 Conclusion

The theory predicts that there are no stress systems that are sensitive to distinctions among peripheral vowels. In the survey presented here, very little independent evidence is found to support claims that such systems exist. Phonological evidence is poor or ambiguous. Acoustic evidence is almost all impressionistic, and generally expressed in uncertain terms.

However, unreliability and imprecision of impressionistic methods does not provide evidence *for* the present theory – i.e. it does not necessitate that there are no stress systems that directly refer to peripheral vowel distinctions. Such a claim is not the point of this section. Instead, the point is simply to observe that currently available phonetic descriptions of stress in languages with putative peripheral-sensitivity are inadequate for drawing any conclusions. On the positive side, the descriptions provide a clear place to look for those wishing to advance the understanding of sonority-driven stress (or the lack of it).

5.3 Central vowel distinctions

This section presents languages reported to have stress systems that are sensitive to central vowels (i.e. 'schwa', usually). The survey comes from 40 languages.

As in section 5.2, the aim of this section is not to present evidence for the theory, as that would require in depth analyses of each case (as for Piuma Paiwan in chapter 3). Instead, the cases known to me are reviewed and classified in terms of the current theory. Future analysis will determine whether the descriptions are accurate.

5.3.1 Schwa systems

The present theory provides a way to classify metrical systems involving schwa. Fundamentally, the present theory recognizes two types of system: (i) schwa is always moraic (i.e. [ə$^\mu$]), and (ii) schwa tends to be non-moraic (i.e. [ᵊ]).

The latter type can be further divided into two subtypes. In the first subtype, schwa is always moraless. In the other subtype, schwa is generally moraless, but can be coerced into being moraic to satisfy certain phonological requirements (e.g. metrical conditions, minimal word restrictions, and so on). The result is that moraic schwa and non-moraic schwa can co-exist in the same phonological system.

In the following sections, I will refer to each scenario in the following terms: '[ə$^\mu$]-system', '[ᵊ]-system', and 'Coercion system'. The scenarios for each system are laid out in Figure 5.1. The constraint $\mathbb{C}$ stands for all constraints that can require schwa to be moraic, such as constraints on foot formation (e.g. FTBINμ) and minimal word restrictions.

Schwa Systems

'[əᵘ]-system'
Schwa is always moraic.
Ranking: HDσ » *μ/ə

Schwa tends to be non-moraic.
Ranking: *μ/ə » HDσ

'[ᵊ]-system'
Schwa is never
moraic.
Ranking: *μ/ə » ℂ,
HDσ

'Coercion system'
Schwa is moraic
under certain
phonological
pressures.
Ranking: ℂ » *μ/ə »
HDσ
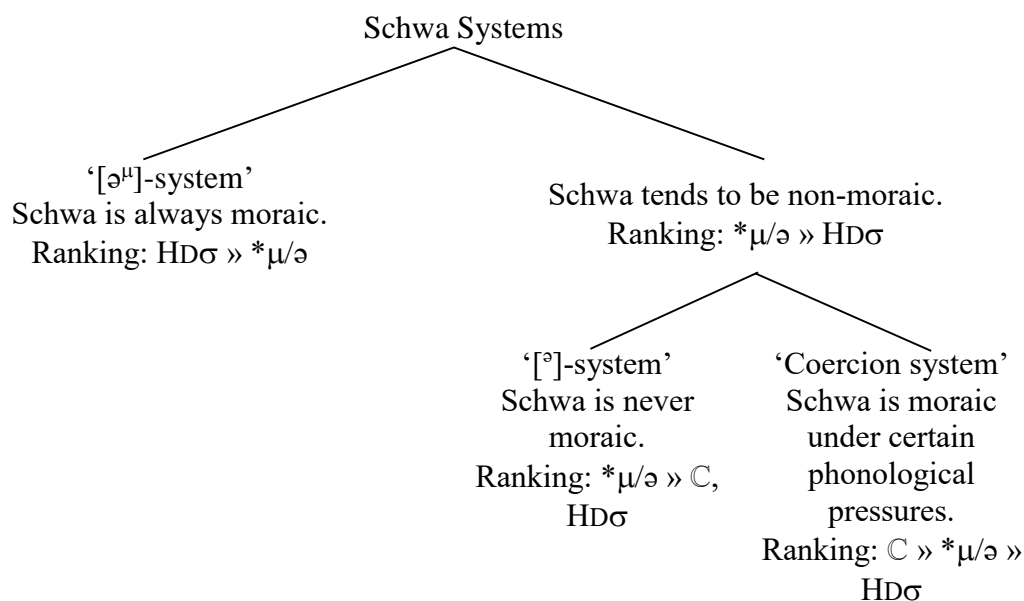
Figure 5.1: Schwa systems.

I will briefly identify the key rankings in each type of system with the caveat that what is presented here is only a sketch for classificatory purposes; much greater detail regarding rankings and constraints is provided in section 5.4 below.

The '[əᵘ]-system' is illustrated in (6). Schwa is always moraic when the headedness constraint HDσ outranks the moraicity constraint *μ/ə. In other words, moraless schwa is banned by HDσ since it requires every syllable to dominate a mora. Candidates (6a) and (6b) fatally violate the constraint HDσ because both of them contain moraless schwa in the output.

(6)   Ranking for the '[əᵘ]-system'

/CVCəCə/	HDσ	*μ/ə
a. (CV́.Cᵊ)Cᵊ	*!*	
b. (CV́.Cə)Cᵊ	*!	*
☞ c. (CV́.Cə)Cə		**

The '[ə]-system' and 'Coercion system' are illustrated in (7) and (8), respectively. In contrast to the '[əᵘ]-system', *μ/ə dominates HDσ so that schwa is moraless. However, the ranking of ℂ makes a crucial distinction between the '[ə]-system' and 'Coercion system'. Recall that ℂ stands for any constraint that demands moras in the same phonological context. Here I use FTBINμ for illustration.

For the '[ə]-system', schwa is always moraless. This means that ℂ is outranked by the constraint *μ/ə. So, having non-moraic schwa is more important than the demands on moras. In this case, FTBINμ is dominated by *μ/ə. Although candidate (7a) violates the lower-ranked constraint FTBINμ, it satisfies *μ/ə.

(7)   Ranking for the '[ə]-system'

/CVCəCə/	*μ/ə	HDσ	FTBINμ
☞ a. (CV́.Cə)Cə		**	*
b. (CV́.Cə)Cə	*!	*	
c. (CV́.Cə)Cə	*!*		

For the 'Coercion system', schwa tends to be non-moraic, but it could be moraic under certain phonological pressures. For example, FTBINμ requires feet to have two moras, so if FTBINμ outranks *μ/ə, then schwa can be forced to be bimoraic for the good of the foot. For example, as shown in (8), the first schwa is forced to be moraic to make the foot minimally bimoraic. However, the second schwa is not forced to have a mora because it is not in the foot, and so it can be non-moraic.

(8)   Ranking for the 'Coercion system'

/CVCəCə/	FTBINμ	*μ/ə	HDσ
a. (CV́.Cˀ)Cˀ	*!		**
☞ b. (CV́.Cə)Cˀ		*	*
c. (CV́.Cə)Cə		**!	

Crucially, moraic and non-moraic schwas display distinct phonetic realizations, as discussed in chapter 2. Since schwa in the '[ˀ]-system' is always moraless, it is never stressed. However, schwa in the '[əᵘ]-system' is able to bear stress, as it is always moraic. Moreover, the stressed and unstressed schwas are expected to be acoustically similar, aside from the influence of stress. For example, if duration is not an acoustic correlate of stress in the '[əᵘ]-system', we would expect the stressed and unstressed schwas, given that they have the same moraic content, to have the same duration. Finally, in the 'Coercion-system', schwa could be either moraic or non-moraic, meaning schwa can be stressed.

The rest of the sections is organized as follows. Sections 5.3.1.1, 5.3.1.2, and 5.3.1.3 present evidence for each schwa system discussed above. Section 5.3.2 provides a more detailed typological survey of 40 languages, with an indication of their possible schwa system(s).

5.3.1.1 '[əᵘ]-system' – Eastern Armenian

Eastern Armenian provides potential evidence for the '[əᵘ]-system'. Haghverdi (2016) conducted a production experiment to examine the stress assignment in Eastern Armenian. Haghverdi (2016) found that stress, contrary to Vaux (1998) and many others, falls consistently on the final syllable of disyllabic words, even if the final syllable contains a schwa.

Many descriptions of Eastern Armenian agree that stress falls on the final syllable unless it contains a schwa, in which case stress retracts to the penult (Khachatryan 1988, Vaux 1998, Sakayan 2007, Dum-Tragut 2009). Examples are from Haghverdi (2016: 2).

(9)   Armenian stress assignment

a. [anúʃ]   'sweet'

b. [anúʃ-ə]   'the sweet'

c. [anúʃ-ət]   'your sweet'

d. [anuʃ-ítsʰ-ət]   'from your sweet'

It should be noted that high vowels [i, u] in monosyllabic roots reduce to schwa in morphologically derived environments (Vaux 1998, Haghverdi 2016). However, the reduction takes place only when the suffix with a non-schwa vowel is added. Otherwise, the reduction is blocked, as shown in (9b-d). Examples below are taken from Haghverdi (2016: 4).

(10)   Reduction of monosyllabic root high vowels in morphologically derived environments

a. [t͡sit]   'sparrow'   c.f. [t͡sət-i]   'of the sparrow'

b. [tun]   'house'   c.f. [tən-it͡sʰ]   'from the house'

c. [d͡ʒuɾ]   'water'   c.f. [d͡ʒəɾ-ɛɾ-ɔv]   'with the waters'

d. [giɾkʰ]   'book'   c.f. [gəɾkʰ-ɛɾ-i-n] 'to the books'

Haghverdi (2016) performed a controlled experiment to examine the acoustic properties of stress in Eastern Armenian. Words of the shape [CVCVC] and [CVCəC] were used to verify the claim that the default stress falls on the final syllable but retracts to penult if there is a schwa. Almost all the stimuli were morphologically-related pairs sharing the same root: they were formed by combining a CVC root with either a -VC case suffix or a -C possessive suffix (in which case a schwa would be inserted, leading to surface CVCəC): e.g. [ha.t-is] 'to my piece' and [ha.t-əs] 'my piece'. All the words were placed within two frame sentences, with the first one in focus position and the second one in non-focus position. One female native speaker was recorded. Five acoustic properties of stress were examined, including duration, intensity, F0, F1, and F2. Vowels [a, ɔ, u, i] were included in the experiment. The prediction is that if stress avoids schwa in the final syllable, V_2 (in [CV_1CV_2C]) and V_3 (in [$CV_3CəC$]) should be stressed, whereas V_1 (in [CV_1CV_2C]) should be unstressed.

The results showed that stress in Eastern Armenian regularly falls on the final syllable, regardless of the vowel quality of the final syllable. The crucial evidence comes from F0, where there is a consistent pitch rise over the final syllable, as shown in Figure 5.2. The L and H tones in the F0 excursion that occurs across all word shapes and vowels occupy virtually the same point in time across all word shapes. Haghverdi (2016: 2) analyzed this pitch rise as involving a LH* tonal contour, where the H* associates with a word-final metrical head. If stress avoids schwa and retracts to the penult, we would expect a rise in pitch on the first syllable of the [$CV_3CəC$] words. However, the fact that the tonal contours are the same for words with different shapes suggests that stress falls on the final syllable.
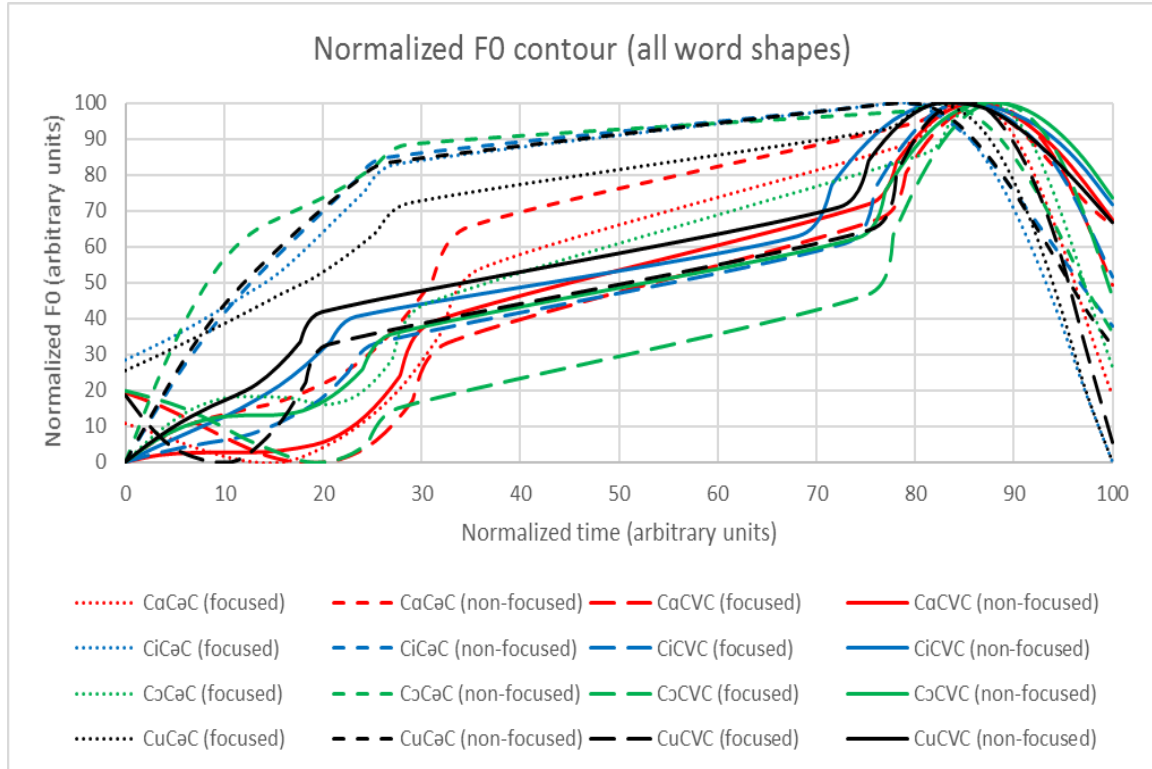
Figure 5.2: Normalized F0 contours for all word shapes and vowels (figure from Haghverdi 2016: 26).

There is no distinction in duration, intensity, F1, or F2 between putatively stressed and unstressed vowels (see Haghverdi 2016 for statistical analyses). Therefore, duration, intensity, F1, and F2 are not acoustic correlates of stress in Eastern Armenian.

Furthermore, Haghverdi (2016) compared the acoustic properties of schwa in different positions: [Cə₁CVC] and [CVCə₄C]. [ə₁] is from high vowel reduction in the first syllable of a [CVCVC] word, whereas [ə₄] is from epenthesis in a suffixed root /CVC-C/. If stress falls on the final syllable, the two schwas must be distinct in one or more acoustic parameter. Results are given in (11). Although [ə₄] is statistically different from [ə₁] in most of the acoustic cues, Haghverdi (2016) discussed their perceptibility and concluded that duration, intensity, and vowel quality do not distinguish the two schwas. Only the mean

pitch of the schwas follows the pattern of both F0 contours observed in [CV₁CV₂C] and [CV₃CəC] words. That is, there is a low tone on [ə₁], and a high tone on [ə₄]. The F0 results suggest that [ə₁] is unstressed while [ə₄] is stressed.

(11)   Acoustic characteristics of schwa in two positions: Cə̱₁CVC vs. CVCə̱₄C

	ə₁	ə₄	Differences
	Cə̱CVC	CVCə̱C	Cə̱CVC vs CVCə̱C
Duration (ms)	49.72 (n=120, sd=8.3)	56.77 (n=240, sd=11.4)	$p < 0.001$
Intensity (dB)	73.47 (n=120, sd=4.6)	75.96 (n=240, sd=3.3)	$p < 0.001$
F1 (Hz)	476.6 (n=120, sd=114.8)	467.2 (n=240, sd=90.1)	$p = 0.396$
F2 (Hz)	1960 (n=120, sd=244.4)	1899 (n=240, sd=250.5)	$p = 0.031$
F0 (Hz) [non-focused]	235.3 (n=60, sd=16.9)	270 (n=120, sd=31.7)	$p < 0.001$
F0 (Hz) [focused]	272.2 (n=60, sd=24.2)	307.6 (n=120, sd=31.1)	$p < 0.001$

Two important results from Haghverdi (2016)'s study suggest that Eastern Armenian belongs to the '[əᵘ]-system' type. First, schwa has the ability to bear stress when it is in the final syllable, indicating that the final schwa is moraic. Second, the penultimate schwa has the same duration as the final schwa. Since duration is not an acoustic correlate of stress, it is reasonable to say that the penultimate schwa has the same moraic content as the final schwa. Therefore, schwas in Eastern Armenian are moraic.

5.3.1.2 '[ᵊ]-system' – Literary Chuvash

Chuvash is probably the best evidence for the '[ᵊ]-system'. Dobrovolsky (1999) performed a production experiment and found that, contrary to Krueger (1961), there is no acoustic evidence for stress in [Cə.Cə] words. This result suggests that schwa in Chuvash is strictly

non-moraic and consequently always unstressed.

Krueger (1961: 86-87) describes stress assignment in Chuvash as follows: (i) the accent is on the last syllable unless this contains the reduced vowel phonemes /ĕ/ or /ă/, (ii) if the last syllable does contain /ĕ/ or /ă/, then the accent is on the syllable immediately preceding, and (iii) if all syllables contain a reduced /ĕ/ or /ă/, then the stress will be on the first syllable. Examples are given in (12). The two reduced vowels /ĕ/ and /ă/ both realize as schwa phonetically, and the only difference is their backness (Krueger 1961: 71-72). I will use schwa to refer to these two vowels in this section. Impressionistically, Krueger (1961: 84) claims that stress in Chuvash words is signaled by a slightly increased intensity of sound, perhaps accompanied with a slight shift of pitch. In short, schwa in Chuvash repels stress but has to be stressed when there is no option.

(12)   Chuvash stress assignment (data from Krueger 1961: 86-87)

   a. [sar.la.ká]   'widely'

   b. [jə.nér.tʃək] 'saddle'

   c. [tə́.tə.mər]   'we got up'

However, Dobrovolsky (1999) argues that there is no default initial stress in Chuvash, as in words with only reduced vowels. Dobrovolsky (1999) measured peak intensity, average intensity, duration, fundamental frequency, and the intensity integral of disyllabic words with the following combinations: FF, FR, RF, and RR (F=syllable with full vowels, R=syllable with reduced vowels). The results show that the first R in RR is not realized by greater peak, average, or total intensity, nor by increased duration. Instead, the

first R has the highest fundamental frequency, which subsequently falls throughout the rest of the word. This initial peak in fundamental frequency is a consistent property of the initial syllable, even when it was not predicted to be stressed. Results are given in Table 5.2. Therefore, what is perceived as a default stress is actually a falling intonation that is assigned at a higher suprasegmental level than word-level stress assignment.

Stress class	Fall on V1	Fall later	Percent
FF	24	13	64.86
FR	31	10	75.60
RF	13	5	72.22
RR	12	5	70.58

Table 5.2: Percentage falling intonation in first vowel or sonorant C following first vowel (table from Dobrovolsky 1999: 541).

Dobrovolsky (1999)'s results can be explained in the present theory by saying that all schwas in Chuvash are moraless. As a consequence, examples (12b) and (12c) should have the following phonetic realizations: [jᵊ.nér.tʃᵊk] 'saddle' and [tᵊ.tᵊ.mᵊr] 'we got up'. Therefore, Chuvash provides potential evidence for the '[ᵊ]-system', as schwas are strictly non-moraic. It should be mentioned that more work needs to done on Chuvash, as Dobrovolsky (1999: 539) admits that only few tokens for each word type were recorded for acoustic analysis.

5.3.1.3 'Coercion system' – Piuma Paiwan

Piuma Paiwan represents the 'Coercion system'. In chapter 3, I have argued that disyllabic words in Piuma Paiwan have the following prosodic structure. Recall that every word in Piuma Paiwan ends in a right-aligned bimoraic trochaic foot.

(13)   Piuma Paiwan's prosodic structure

    a.   [(CÝ$^{\mu}$.CV$^{\mu}$)]

    b.   [(CÝ$^{\mu}$.CV$^{\mu}$C)]

    c.   [C$^{\circ}$(CÝ:$^{\mu\mu}$)]

    d.   [C$^{\circ}$(CÝ:$^{\mu\mu}$C)]

    e.   [(CÝ$^{\mu}$.Cə$^{\mu}$C)]

    f.   [C$^{\circ}$(Cə́:$^{\mu\mu}$C)]

Schwa in Piuma Paiwan is non-moraic as it repels stress in the penultiamte position, as shown in (13c), (13d), and (13f). However, due to the pressure of the constraint FTBINμ, schwa cannot always be non-moraic, as evident in (13e) and (13f). That is, schwa is forced to be moraic to satisfy the requirement that a foot must be bimoraic, if no other option is available. For example, words with the shape [Cə.CVC] and [Cə.CəC] all contain a schwa in the penult. The sole difference between the two is the final vowel. As mentioned above, a foot must be bimoraic. So, the strategy to satisfy this requirement is to enable the last vowel to have two moras. Thus, the ultimate schwa in [Cə.CəC] words has to be bimoraic, which is the same as the ultimate V in [Cə.CVC] words. The constraint ranking argued in chapter 3 is repeated in (14).

(14)   Bimoraic schwa ranking

/ləʎət/	FTBINμ	*μ/ə	HDσ	ID-LENGTH
☞ a. [ˀ(ʎə́:t)		*	*	*
b. (lə́.ʎət)		**!		
c. ([ˀ.ʎˀt)	*!		**	

Crucially, candidate (14c) is eliminated by FTBINμ because the foot does not have two moras. In short, Piuma Paiwan represents a mixed system, where moraic and non-moraic schwas coexist in the same phonological system.

5.3.2 Other languages

This section presents a survey of descriptions of languages in which stress avoids central vowels. 40 such languages are described. In Table 5.3, I provide information about stress assignment under different conditions.

The descriptions are classified in Table 5.3 by examining each description and determining where stress would fall in words with the shape indicated. I take Woolams (1996)'s description of Karo Batak for illustration. The default stress falls on the penultimate syllable (i.e. [CV.CV́.CV]). However, when the penult contains a schwa, stress moves to the final syllable (i.e. [CV.Cə.CV́]). When both penult and ultima contain a schwa, stress still falls on the final syllable (i.e. [CV.Cə.Cə́]). When a word contains only schwas, stress remains on the final syllable (i.e. [Cə.Cə.Cə́]).

Information about syllable structure is also provided. If one of the above word types is not found in the description, a question mark appears in the table. Some languages have more than one stress description; they are also included in the survey. Moreover, this survey only focuses on trisyllabic words, as they provide a clear pattern of stress movement. If trisyllabic words are not mentioned in the description, disyllabic words are used instead. Finally, my theory predicts three schwa systems: '[əᵘ]-system', '[ə]-system', and 'Coercion system'. Here I mark each language with its possible type based on the descriptions, with [əᵘ] for the '[əᵘ]-system', [ə] for the '[ə]-system', and M for the 'Coercion-system'. Some

of the languages are ambiguous in what prosodic system they belong to, so all are indicated in the survey.

It should be mentioned that the stress pattern in some languages has already received a great deal of attention recently, such as Eastern Mari (Lehiste *et al*. 2005), French (see Özçelik 2016 for a review), Indonesian (see Goedemans & van Zanten 2007 for a review), Witsuwit'en (Hargus 2001, 2005), and Yakima Sahaptin (Hargus 2001). Some research suggests that the apparent central vowel avoidance stress pattern should be reanalyzed as long vs. short vowels in terms of their phonetic and phonological behaviors, as in Witsuwit'en (Hargus 2001, 2005) and Yakima Sahaptin (Hargus 2001). Some research even claims that word-level stress does not exist in some languages, as in Indonesian (e.g. Goedemans & van Zanten 2007) and French (e.g. Özçelik 2016), arguing that what is perceived as stress in these languages is actually the intonational tune. As a result, there is no sonority-driven stress in these languages at all. Finally, Lehiste *et al*. (2005) conducted a detailed production experiment showing that stress is lexicalized in Eastern Mari.

As Table 5.3 shows, almost all the languages belong to the 'Coercion-system'. This is not to say that the 'Coercion-system' represents the majority of the typology. The result is probably due to the purpose of the survey, as it aims to report languages that avoid central vowels. So, this survey is not an indication of typological frequency. Instead, it shows that future work is needed to clarify the status of central vowel(s) in each language.

Systems: [ᵊ] vs. [əᵘ] vs. M for 'Coercion-system'

Language	Version	Default	Schwa in default	Schwa default and 2nd default	All schwas	Syllable	Notes
Karo Batak (Austronesian)	Woolams (1996)	CVCV́CV	CVCəCV́	CVCəCə́	CəCəCə́	(C)(C)V(C)(C)	M
Patep (Austronesian)	Adams & Lauck (1975), Vissering (1993)	CV́CVCV	CəCV́CV	CəCəCV (?)	CəCəCə (?)	(C)(C)V(C)	M or [ᵊ]
Ngadha (Austronesian)	Djawanai (1983)	CVCV́CV	CVCəCV́	CVCəCə (?)	CəCəCə (?)	(C)V	M or [ᵊ]
Mari, Northwest (Uralic)	Ivanov & Tuzarov (1970) Kenstowicz (1997)	CVCV́CV	CV́CəCV	CəCə́CV	Cə Cə́Cə ~ Cə́CəCə	?	M
Mari, Eastern or Meadow Mari (Uralic)	Riese et al. (2010)	CVCVCV́	CV́CVC$_v$ (v = ə, e, o, ö)	CV́C$_v$C$_v$	C$_v$́C$_v$C$_v$	?	M
	Lehiste et al. (2005)	Lexical stress					
Mari, Literary (Uralic)	Gruzov (1960) Kenstowicz (1997)	CVCV́CV	CV́CəCV	Cə́CəCV	Cə́CəCə	?	M
Mari, Western or Hill Mari (Uralic)	Itkonen (1955)	CVCV́CV	CV́CCəCV	CəCə́CCVC	CəCə́CəC	?	M
Lamang (Afro-Asiatic)	Wolff (1983, 2015)	CVCV́CV	CV́CəCV	CəCə́CCV	CəCəCə (?)	?	M
Moro (Niger-Congo)	Black & Black (1971)	CVCV́CV	CV́CəCV (cf. CəCV́)	CəCəCV (?)	CəCəCə (?)	(C)(C)V(C)	M or [ᵊ]

Language	Version	Default	Schwa in default	Schwa default and 2nd default	All schwas	Syllable	Notes
Lillooet (Salish)	van Eijk (1981, 2013)	CV́CVCV	CᵥCV́CV (v = ə, ʌ)	CᵥCᵥCV́	Cᵥ́CᵥCᵥ	CVC(C) (roots)	M
Sarangani Manobo (Austronesian)	DuBois (1976)	CVCV́CV	CVCəCV́	CVCə́Cə	CəCəCə (?)	(C)CV(C)	M
Piuma Paiwan (Austronesian)	(Chen 2009a, b), Yeh (2011)	CVCV́CV	CVCəCV́	CVCəCə́C	CəCəCə́C (?)	(C)(C)V(C)	M
Yil (Pama-Nyungan)	Martens & Tuominen (1977)	CV́CVCV	CəCV́CV ~ Cə́CVCV	CəCəCV (?) (cf. Cə́Cə)	CəCəCə (?)	(C)(C)V(C)(C)	M
Sentani, Eastern (East Bird's Head-Sentani)	Cowan (1965)	CVCV́CV	CVCəCV (?) (cf. CVCə́CCV CV́CCəCV)	CəCə́CV (cf. Cə́CCəCV CVCCV́CV)	CəCəCə (?)	(C)V(C)	?
Sentani, Central (East Bird's Head-Sentani)	Elenbaas (1999)	CVCV́CV CVCV̀CV́CV	CVCə́CV CV̀CəCV́CV	CəCəCV (?) CəCə̀CV́CV	CəCəCə (?)	(C)V(C)	M Secondary stress sensitive to schwa
Surmiran (Romansh)	Anderson (2008)	CVCVCV́	CVCV́CəC (**C** = r, l, n, s) CVCVCə́C (**C** ≠ r, l, n, s)	CVCəCCəC (?)	CəCCəCCəC (?)	?	M or [ᵊ]
Cowichan (Salish)	Bianco (1998)	CV́CVCV	CəCV́CV	Cə́CəCV	Cə́CəCə	?	M
Witsuwit'en (Athabaskan)	Hargus (2001, 2005)	CV́CVCV̀	CəCV́CV	Cə́CəCV̀	Cə́CəCə̀	?	M

Language	Version	Default	Schwa in default	Schwa default and 2nd default	All schwas	Syllable	Notes
Siraiki (Indo-Aryan)	Shackle (1976)	CV́CVCV̀	C_VCV́CV (v = ɪ, ʊ, ʌ)	C_VC_VCV (?)	$C_VC_VC_V$ (?)	?	M or [ᵊ]
Javanese (Austronesian)	Herrfurth (1964) Horne (1974)	CV́CV	CəCV́	CəCə́C CVCəCə́C	CəCəCəC (?)	(C)(C)V(C)	M
Delhi Hindi (Indo-Aryan)	Pierrehumbert & Nair (1996)	CVCVCV (?) CV́CV	CVCəCV (?) CəCV́	CVCəCə (?) Cə́CCəC	CəCəCə (?)	?	M
Au, Central (Toricelli)	Scorza (1973)	CV́CVCV CVCVCV́CV	C_VCVCV (?) (v = ɨ, ʌ)	C_VC_VCV (?)	$C_VC_VC_V$ (?)	(C)(C)V(C)(C)	?
	Scorza (1985)	CV́CVCV	C_VCVCV (v = ɨ, ʌ)	C_VC_VCV (?)	Cv́C_VC_V	?	M
	Scorza (1992)	CV́CVCV	C_VCVCV (?) (v = ɨ, ə)	C_VC_VCV (?)	$C_VC_VC_V$ (?)	(C)(C)V(C)(C)	?
Paipai (Yuman)	Joel (1966)	CVCVCV́	CVCVCə (?)	CVCəCə (?)	CəCəCə (?)	?	[ᵊ] No data; see 3.2.2
Alyutor (Chukotko-Kamchatkan)	Kodzasov & Muravyova (1978)	CVCV́CV	CV́CəCV	CəCəCV (no stress)	CəCəCə (no stress)	CV(C)	[ᵊ]
Lushootseed, Northern (Salish)	Hess (1977)	CV́CVCVC	CəCV́CV	CəCəCV (?) (cf. Cə́CəC)	CəCəCəC (?) (cf. Cə́CəC)	?	M
Khanty (formerly "Eastern Vach Ostyak") (Uralic)	Gulya (1966)	CVCVCV (?) (cf. CV́C$_V$Cv̀)	C_VCV́CV (v = ə, ŏ, ă, o)	C_VC_VCV (?) (cf. Cv́C_V)	$C_VC_VC_V$ (?)	?	M

Language	Version	Default	Schwa in default	Schwa default and 2nd default	All schwas	Syllable	Notes
Indonesian (Austronesian)	Goedemans & van Zanten (2007)	No stress				?	
	Halim (1981)	No stress				(C)V(C)	
	Prentice (1990)	CV́CVC	CəCV́C	CVCəCə (?)	CəCəCə (?)	?	M or [ᵊ]
	Cohn (1989)	CVCV́CV	CV́CəCV (cf. CəCV́)	CəCəCV́	CəCəCə (?)	?	M or [ᵊ]
	Macdonald (1976)	CVCV́CV	CVCəCV́	CVCəCə (?)	CəCəCə (?)	CV(C)	M or [ᵊ]
	Lapoliwa (1981)	CVCV́CV	CV́CəCV	CəCəCV́	CəCəCəC (?) (cf. CəCáC)	?	M
	Laksman (1994)	CV́CV	Cə́CV			?	M or [əᵘ]
Nek (Papuan)	Linnasalo (2003)	CV́CVCV	CəCVCV (?) (cf. CəCV́)	CəCəCV́	CáCəCə	(C)(C)V(A)(C) (A=approximant)	M
Nankina (Finisterre)	Spaulding & Spaulding (1994)	CV́CV́CV (cf. CV́CV)	CɨCVCV (?) (cf. CɨCV́)	CɨCɨCV (?)	CɨCɨCɨ (?)	(C(C))V((C)C)	M or [ᵊ]
Chuvash, literary (Turkic)	Krueger (1961)	CVCVCV́	CVCV́C_v (v = ĕ, ă)	CV́$C_v$$C_v$	C_v́$C_v$$C_v$	?	M
	Dobrovolsky (1999)	CV́CV	C_vCV́ CV́C_v (v = ĕ, ă)		$C_v$$C_v$ No stress	?	[ᵊ]

Language	Version	Default	Schwa in default	Schwa default and 2ⁿᵈ default	All schwas	Syllable	Notes
Armenian, Western & Eastern (Indo-European)	Vaux (1998)	CVCVCV́	CVCVCə (?) (cf. CV́Cə)	CVCəCə (?)	CəCəCə (?) (cf. Cə́CəC)	?	M
Armenian, Eastern (Indo-European)	Sakayan (2007)	CVCVCV́	CVCV́Cə	CVCəCə (?)	CəCəCə (?)	?	M or [ᵊ]
Armenian, Karabagh (Indo-European)	Vaux (1998)	CVCV́CV	CVCəCV́ (cf. CV́CVCə, CəCV́, CV́Cə)	CVCəCə (?)	CəCəCə (?) (cf. Cə́Cə)	?	M
French, Standard (Indo-European)	Dell (1980)	CVCVCV́	CVCV́Cə	CVCəCə (?)	CəCəCə (?)	?	M or [ᵊ]
	Özçelik (2016)	No stress					
Sahaptin, Yakima (Sahaptian)	Hargus (2001)	a. CV́CV (default) b. CVCV́ (lexically specified)	a. CɨCV (9%) b. CVCɨ (0%)	a. CɨCɨ (0%) b. CiCɨ (0%)	No	?	? 119 CVCV roots examined
Nganasan, Avam (Uralic)	Vaysman (2009)	CVCV́CV	CV́CəCV	see 3.2.4	see 3.2.4	?	M
Ma Manda (Finisterre)	Pennington (2013)	CV́CVCV̀	see 3.2.4	see 3.2.4	see 3.2.4		M
Gujarati (Indo-Aryan)	See chapter 4						

Language	Version	Default	Schwa in default	Schwa default and 2nd default	All schwas	Syllable	Notes
Yimas (Lower Sepik)	Foley (1991)	CV́CVCV	CiCV́CV	Cí CiCV	CíCiCiC	(C)(C)V(C)(C)	M
Kobon (Madang)	Davies (1981)	CVCV́CV	CVCᵥCV (?) (v = ə, ɨ)	CVCᵥCᵥ (?)	CᵥCᵥCᵥ (?) (cf. CiCCíCiC)	(C)V(C)	M
	Kenstowicz (1997)	CVCV́CV	CVCᵥCV (?) (v = ə, ɨ)	CVCᵥCᵥ (?)	CᵥCᵥCᵥ (?)	?	M see 3.2.4

Table 5.3: Typological survey of central vowels and stress assignment.

5.3.2.1 Moraic schwa '[əᵘ]' systems

As discussed for Eastern Armenian in section 5.3.1.1, evidence for the '[əᵘ] system' requires a comparison between stressed and unstressed schwas. Under such a system, unstressed schwa is expected to have the same duration as stressed schwa, excluding the influence of stress and other non-stress factors. Other than Eastern Armenian, one possible candidate for the '[əᵘ] system' is found in Laksman (1994)'s experimental study on Indonesian. Laksman (1994) conducted a production experiment to examine the location of stress in Indonesian. Disyllabic words of the shape [CV.CV(C)] and [Cə.CV] were used to test whether stress avoids schwa in the penultimate syllable. The result shows that the fundamental frequency of the penultimate vowel is always the highest (independently of the type of vowel). Laksman then concludes that stress is always on the penultimate syllable and that the most robust stress correlate is fundamental frequency. Crucially, the central vowel [ə] can be stressed as well as any other vowel.

Laksman (1994)'s finding is similar to Eastern Armenian in that F0 plays the most important role in signaling the location of stress. Moreover, schwa receives stress when it is in the default stress position. However, what is missing in Laksman (1994)'s study is that it didn't compare the acoustic properties of stressed and unstressed schwas. It is possible that there is no significant acoustic difference between stressed and unstressed schwas except for F0. Therefore, Indonesian, based on Laksman (1994)'s result, could be evidence for the '[əᵘ]-system'.

5.3.2.2 Non-moraic schwa '[ᵊ]' systems

In the current survey, 10 languages (from 12 descriptions) can be analyzed as a '[ᵊ] system'.

They are Patep (Adams & Lauck 1975, Vissering 1993), Ngadha (Djawanai 1983), Moro (Black & Black 1971), Siraiki (Shackle 1976), Paipai (Joel 1966), Alyutor (Kodzasov & Muravyova 1978), Nankina (Spaulding & Spaulding 1994), Eastern Armenian (Sakayan 2007), Standard French (Dell 1980), and Indonesian (Prentice 1990, Macdonald 1976). Notice that there are multiple descriptions for French, Eastern Armenian, and Indonesian, as shown in Table 5.3. Only descriptions that match the property of the '[ə]-system' are listed here.

Unfortunately, not much can be said about these languages at this moment. Almost all the descriptions only report stress patterns where there is a central vowel in the default position. For example, in Ngadha (Djawanai 1983), the default stress position is the penult (i.e. [CVCV́CV]). When the penult contains a schwa, stress falls on the final syllable (i.e. [CVCəCV́]). There is no information about words with the shape [CVCəCə] and [CəCəCə]. So, it is not clear whether schwa can ever be stressed. It is also possible that there are restrictions on multiple schwas in the same word so such words may not be observable.

Alyutor (Kodzasov & Muravyova 1978) and Paipai (Joel 1966) are probably the most likely to belong to the '[ə] system'.

In Alyutor, stress falls on the peninitial syllable by default, as in [vi.tá.tək] 'to work' and [vi.lúl.ŋən] 'ear'.[2] However, when the peninitial syllable contains a schwa, stress falls on the initial syllable, as in [tíl.pə.gal] 'shoulder' and [jí.lə.jil] 'tongue'. Crucially, Kodzasov & Muravyova (1978: 47-48) mention that "if both the first and the second syllable are light, stress is absent altogether, e.g. [təjələn] 'I gave it', [nəkəkagin] 'hot'"

For Paipai, Joel (1966: 10) notes that "there is a tendency for final syllables to be

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[2] In disyllabic words, stress always falls on the initial syllable. I assume that the language is iambic, but has an overriding ban on final stress.

stressed, so long as they do not correspond to suffixed elements and are not breve syllables."

Joel (1966: 10) further mentions that "breve syllables are always unstressed; full syllables

are always stressed." Breve syllable refers to syllables that contain a schwa.

If Kodzasov & Muravyova (1978)'s and Joel (1966)'s descriptions are accurate,

then Alyutor and Paipai are potentially good candidates for the '[ə]-system'. Specifically,

in terms of the present theory, Alyutor requires schwas to be non-moraic, and also requires

a left-aligned iambic foot ([(vi.tá)tək]). The foot can contract as in [(tílpə)gal]), but it

cannot move away from the right edge. So, for /nəkəkagin/, the output cannot be

*[nə(kəká)gin)]. Instead, the foot is trapped at the left edge, so the output is [(nəkə)kagin],

with a headless foot. A sketch of this analysis is provided in the tableau below.

The tableau shows how /nəkəkagin/ can emerge with a headless foot. Crucially, the

constraint *μ/ə outranks HEADEDNESS-σ (abbreviated to HD-σ) and HEADEDNESS-FT –

this ranking means that candidate (15a) with a moraic schwa cannot win. Candidate (15b)

is eliminated by ALLFTL because the foot is not leftmost in the PrWd. Candidate (15c) is

eliminated by FTMAX-σ – a constraint that limits the maximum size of feet to two syllables

(this restriction may also be required by GEN). So, candidate (15d) wins, with a headless

left-aligned foot and only nonmoraic schwas.

(15)   A preliminary analysis of Alyutor stress

/nəkəkagin/	FTMAX-σ	*μ/ə	ALLFTL	HD-σ	HD-FT
a. (nəkə́ᵘ)kagin		*!		*	
b. nə(kəká)gin			*!	* *	
c. (nəkəká)gin	*!			* *	
☞ d. (nəkə)kagin				* *	*

However, descriptions of both Alyutor and Paipai are impressionistic, and no stress

data is provided in Joel (1966)'s description. There is also no phonological evidence referring to stress in either description. The only description of the phonetic realization of stress is found in Kodzasov & Muravyova (1978), in which duration and intensity function as cues for stress in Alyutor. Future study is needed even though the descriptions fit the property of the '[ᵊ]-system'.

5.3.2.3 Coercion systems

In the survey, 35 languages (from 49 descriptions) are marked as potential examples of the 'Coercion system'. As those descriptions state, stress avoids central vowels in default position, but in situations where a word contains more than one schwa, one of the schwas is stressed. In the present theory, these languages can be analyzed as having non-moraic and moraic schwas in the same phonological system.

However, few descriptions provide a complete statement about stress assignment in different conditions (e.g. information about words of the shape [CəCəCə] is missing in DuBois 1976's description of Sarangani Manobo). So, the following discussion is based on languages where the description for trisyllabic words is complete, including Karo Batak (Woolams 1996), Northwest Mari (Ivanov & Tuzarov 1970, Kenstowicz 1994), Eastern Mari (Riese *et al*. 2010), Literary Mari (Gruzov 1960, Kenstowicz 1994), Western Mari (Itkonen 1955), Lillooet (van Eijk 1981, 2013), Cowichan (Bianco 1998), Witsuwit'en (Hargus 2001, 2005), Literary Chuvash (Krueger 1961), and Yimas (Foley 1991).

● *Karo Batak and Literary Mari*

One property that Karo Batak (Woolams 1996) and Literary Mari (Gruzov 1960,

Kenstowicz 1994) share is that stress always avoids schwa in default position no matter what the word shape is. So, one could analyze these two languages along the lines of Piuma Paiwan (see chapter 3). That is, we could posit a default right-aligned trochaic foot in Karo Batak, and a default left-aligned iambic foot in Literary Mari, as shown in (16). The schwa in the penultimate syllable is moraless, so it is never stressed. However, when schwa is in the head position of a foot (e.g. [CVCəCə́] in Karo Batak and [Cə́CəCV] in Literary Mari), it is forced to be bimoraic and therefore receives stress. Under this analysis, the schwa at the right edge in Karo Batak and the schwa at the left edge in Literary Mari are moraic. The other schwas are moraless.

(16)   Foot structure for Karo Batak and Literary Mari: Analysis I

      <u>Karo Batak</u>   <u>Literary Mari</u>

      CV(CV́ᵘ.CVᵘ) (CVᵘ.CV́ᵘ)CV

      CV.Cə(CV́ᵘᵘ) (CV́ᵘᵘ)Cə.CV

      CV.Cə(Cə́ᵘᵘ) (Cə́ᵘᵘ)Cə.CV

      Cə.Cə(Cə́ᵘᵘ) (Cə́ᵘᵘ)Cə.Cə

Following Piuma Paiwan, stress assignment in Karo Batak can be explained by ranking FTBINμ, FTBIN, TROCHEE, ALLFTL over *μ/ə. So, every foot in Karo Batak is bimoraic and only branches once at either the foot or syllable level. On the other hand, Literary Mari differs from Karo Batak in that it has a left-aligned iambic foot. Hence, the relevant constraints here are IAMB and ALLFTL, but the constraint ranking remains the same.

This type of analysis predicts that for Karo Batak words with a final schwa, such as /CVCVCə/, the output should have the form [CV(CV́.Cə^μ)]. The foot has to satisfy FTBINμ, so the schwa is required to be monomoraic. Similarly, for Literary Mari, /CəCVCV/ is predicted to have the output form [(Cə^μ.CV́)CV]. The initial schwa is monomoraic due to pressure from FTBINμ. For complete analysis, see chapter 3 on Piuma Paiwan.

The other possible analysis is that Karo Batak has a default left-aligned iambic foot, whereas Literary Mari employs a default right-aligned trochaic foot. Under this analysis, all the syllables are parsed into a foot when a word contains at least one schwa, as shown in (17). Apparently, all feet are bimoraic and they do not shrink to a monosyllabic foot.

The crucial distinction between the two analyses is the moraic content of the schwa. Under the first analysis, schwa is bimoraic when it is in the head position of a foot. However, under the second analysis, schwa is monomoraic when it is in the head position of a foot. As none of the descriptions for Karo Batak and Literary Mari provide a phonetic examination of schwa in different positions, future study is required.

(17)   Foot structure for Karo Batak and Literary Mari: Analysis II

Karo Batak   Literary Mari

(CV.CV́)CV   CV(CV́.CV)

(CV.Cᵒ.CV́)   (CV́.Cᵒ.CV)

(CV.Cᵒ.Cə́^{μ})   (Cə́^{μ}.Cᵒ.CV)

(Cə^μ.Cᵒ.Cə́^{μ})   (Cə́^{μ}.Cᵒ.Cə^μ)

It should be noted that the status of stress in Karo Batak has been questioned in recent research. Goedemans & van Zanten (2014) set up a series of criteria (e.g. stress is reported to be very weak and unstable) to evaluate descriptions of stress assignment in Austronesian languages. Based on their criteria, they mark Karo Batak (Woolams 1996) as clearly suspicious with respect to the status of stress.

● *Northwest Mari*

The stress pattern of Northwest Mari (Ivanov & Tuzarov 1970, Kenstowicz 1994) and Western Mari (Itkonen 1955) differs from that of Literary Mari in that stress is not always repelled to the left edge of the word. For words of the shape [CəCəCV] and [CəCəCə], stress still falls on the penult. Note that there is free variation for [CəCəCə] words in Northwest Mari.

The stress pattern in Northwest Mari and Western Mari can be explained by postulating an iambic foot aligned with the left edge of the word. The crucial ranking is that both IAMB and ALLFTL outrank *μ/ə, so the foot has to align with the left edge of the word and satisfy IAMB. For words of the shape [CəCəCV] and [CəCəCə], the schwa in the penult has to be moraic as it is the head of the iambic foot.

(18)   Foot structure for Northwest Mari and Western Mari

(CV.CV́)CV

(CV́)Cə.CV

(Cə.Cə́$^{\mu}$)CV

(Cə.Cə́$^{\mu}$)Cə

(19) /CəCəCV/ as input

/CəCəCV/	IAMB	ALLFTL	*μ/ə	HDσ
☞ a. (Cᵊ.Cə́)CV			*	*
b. (Cə.Cə́)CV			**!	
c. Cᵊ(Cᵊ.CV́)		*!		*
d. (Cᵊ.Cᵊ)CV	*!			**

Candidate (19b) is eliminated by ALLFTL because it does not align with the left edge of the word. Candidate (19d) fatally violates IAMB because there is no head in the foot. Finally, candidate (19b) differs from candidate (19a) in that it has two moraic schwas, so it is ruled out by *μ/ə. The same analysis applies to [CəCəCə] words.

The foot shrinks in /CVCəCV/ words due to the pressure from IAMB. Candidate (20d) fatally violates IAMB because it has a trochaic foot. Both candidates (20b) and (20c) have a perfect iambic foot. However, (20b) and (20c) incur one violation of *μ/ə and ALLFTL, respectively. The winner – candidate (20a) – avoids the problems of candidates (20b)-(20d), but at the cost of having a monosyllabic foot.

(20) /CVCəCV/ as input

/CVCəCV/	IAMB	ALLFTL	*μ/ə	HDσ
☞ a. (CV́)Cᵊ.CV				*
b. (CV.Cə́)CV			*!	
c. CV(Cᵊ.CV́)		*!		*
d. (CV́.Cᵊ)CV	*!			*

• *Cowichan, Witsuwit'en, and Yimas*

Cowichan (Bianco 1998), Witsuwit'en (Hargus 2001, 2005), and Yimas (Foley 1991) share the same stress pattern: stress falls on the initial syllable by default, and moves to the penultimate syllable when there is a schwa. However, stress stays at the default position

when the antepenult and penult contain a schwa.

To account for the stress pattern, one could posit a disyllabic foot aligned with the left edge of the word. Essentially, TROCHEE and FTBINσ dominate *μ/ə in order for a trochaic foot to have two syllables.

(21)   Foot structure for Cowichan, Witsuwit'en, and Yimas

(CV́.CV)CV

Cə(CV́.CV)

(Cə́ᵘ.Cə)CV

(Cə́ᵘ.Cə)Cə

Due to pressure from TROCHEE and FTBINσ, the first schwa in [CəCəCV] words becomes the head of the foot. In the following tableau, candidate (22b) violates TROCHEE because the foot has no head. Candidate (22c) is ruled out because the foot is monosyllabic. Candidate (22d) incurs two violations of *μ/ə because there are two moraic schwas. Finally, candidate (22e) is eliminated by ALLFTL since it is not at the left edge of the word.

(22)   /CəCəCV/ as input

/CəCəCV/	TROCHEE	FTBINσ	*μ/ə	ALLFTL	HDσ
☞ a. (Cə́.Cə)CV			*		*
b. (Cə.Cə)CV	*!				**
c. Cə.Cə(CV́)		*!		**	**
d. (Cə́.Cə)CV			**!		
e. Cə(Cə́.CV)			*	*!	*

Recall that stress avoids schwa in words of the shape [CəCVCV]. So, in order to satisfy

TROCHEE and FTBINσ, a disyllabic trochaic foot is placed at the right edge of the word. Candidate (23b) violates TROCHEE, and candidates (23d) and (23e) violate FTBINσ. Candidate (23c) does not violate TROCHEE or FTBINσ, but it includes a moraic schwa in the foot.

(23)   /CəCVCV/ as input

/CəCVCV/	TROCHEE	FTBINσ	*μ/ə	ALLFTL	HDσ
☞ a. Cᵊ(ĆV.CV)				*	*
b. (Cᵊ.ĆV)CV	*!				*
c. (Cə́.CV)CV			*!		
d. Cᵊ(ĆV)CV		*!		*	*
e. (Cə́)CV.CV		*!	*		

Hargus (2001, 2005) argues that the avoidance of schwa in Witsuwit'en is because schwa is phonetically and phonologically different from peripheral vowels. Hargus (2001) measured vowel duration and found that schwa is the shortest vowel (46ms) – far shorter than high vowels [i u] (121ms) and mid vowels [e o] (144ms). Hargus (2001) further investigated the phonological behavior of schwa and peripheral vowels, finding that central vowels could not occur long or finally, and voicing alternations were avoided with central vowel roots. It is possible that the phonetic brevity and phonological restrictions on schwa can be related to its lack of a mora, much as was shown for Piuma Paiwan.

Hargus (2005) further investigates whether vowel quality plays a role in Witsuwit'en stress, comparing word initial [Cə] syllables followed by [Cə] vs. [Ci], [Ca], and [Cu] syllables. The predicted stress pattern is #[Cə́.Cə] and #[Cə.ĆV]. That is, an initial schwa is stressed when it is followed by another schwa, but an initial schwa is unstressed when followed by a full vowel. The results showed that across speakers there were no significant differences in duration, pitch, or energy. Hargus (2005: 406) notes, however,

that "at the individual level, seven of nine speakers had one or more of the predicted characteristics of stress for syllables before reduced vowels." The results suggest that vowel quality might not be a factor in Witsuwit'en stress assignment.

• *Lillooet*

Lillooet (van Eijk 1981, 2013) shows a stress pattern where stress avoids central vowels and falls on the closest full vowel. When there is no full vowel in a word (i.e. [CəCəCə]), stress falls on the default initial syllable. The stress pattern can be modeled by ranking TROCHEE above *μ/ə. Moreover, *μ/ə dominates FTBINμ, ALLFTL, IAMB, FTBINσ, and HDσ.

(24)   Foot structure for Lillooet

(CÝ.CV)CV

Cə(CÝ.CV)

Cə.Cə(CÝ)

(Cə́ᵘ)Cə.Cə

For [CəCəCV] words, the last syllable is stressed. Any foot that does not satisfy TROCHEE is ruled out, as can be seen in candidate (25c). However, when a trochaic foot contains a moraic schwa, as in candidates (25b) and (25d), it is eliminated by *μ/ə. So, the only option is to have a monosyllabic foot containing the full vowel, even though it violates FTBINμ, ALLFTL, and FTBINσ. The optimal output is (25a).

(25)   /CəCəCV/ as input

/CəCəCV/	TROCHEE	*μ/ə	FTBINμ	ALLFTL	FTBINσ	HDσ
☞ a. Cˤ.Cˤ(CV́)			*	**	*	**
b. (Cə́.Cə)CV		*!*				
c. (Cˤ.Cˤ)CV	*!		*			**
d. (Cə́.Cˤ)CV		*!	*			*

The output for [CəCəCə] words is particularly interesting as it has a monosyllabic foot containing the initial schwa; this is due to the emergent effect of IAMB. Both candidates (26a) and (26b) have the same violation profile except that (26b) violates IAMB. For a foot to satisfy both TROCHEE and IAMB, it must be monosyllabic. Candidate (26e) also has a monosyllabic foot, but it is one syllable away from the left edge of the word, thus violating ALLFTL.

(26)   /CəCəCə/ as input

/CəCəCə/	TROCHEE	*μ/ə	FTBINμ	ALLFTL	IAMB	FTBINσ	HDσ
☞ a. (Cə́)Cˤ.Cˤ		*	*			*	**
b. (Cə́.Cˤ)Cˤ		*	*		*!		**
c. (Cˤ.Cˤ)Cˤ	*!				*		
d. (Cə́.Cə)Cˤ		**!			*		*
e. Cˤ(Cə́)Cˤ		*	*	*!		*	**

• *Literary Chuvash and Eastern Mari*

Finally, Literary Chuvash (Krueger 1961) and Eastern Mari (Riese *et al*. 2010) display a 'default-to-opposite' stress system: stress falls on the final syllable when there is no central vowel, but it falls on the initial syllable when the word contains only central vowels. The sole difference between the two lies in the stress position in [CVCVC$_V$] words, with

Literary Chuvash on the penultimate syllable and Eastern Mari on the initial syllable.

Literary Chuvash is similar to Lillooet because stress seeks out the closest full vowel to the default stress position. So, IAMB outranks *μ/ə, and *μ/ə dominates FTBINμ, ALLFTR, TROCHEE, FTBINσ, and HDσ. The remaining issue is the stress pattern in [CəCəCə] words, as the current analysis would predict a monosyllabic foot aligned with the right edge of the word (i.e. *[Cᵊ.Cᵊ(Cə́ᵘ)]).

It is possible that there is an additional pressure for the initial syllable to keep its mora (e.g. through a positional markedness requirement – Smith 2004). If so, that pressure would favor [(Cə́ᵘ)CᵊCᵊ] over *[Cᵊ.Cᵊ(Cə́ᵘ)].

(27)   Foot structure for Literary Chuvash

CV(CV.CV́)

(CV.CV́)Cᵊ

(CV́)Cᵊ.Cᵊ

(Cə́ᵘ)Cᵊ.Cᵊ

Eastern Mari differs from Literary Chuvash slightly. Stress falls on the final syllable unless it contains a reduced vowel, in which case it falls on the initial syllable. So, in /CVCVCə/ words, stress is initial: [CV́CVCə]. It is possible that Eastern Mari imposes categorical requirements on stress position, i.e. stress must fall on the rightmost syllable, and if it cannot, it must fall on the leftmost syllable.

However, other studies have argued that stress in these two languages differs from Riese *et al.* (2010)'s and Krueger (1961)'s descriptions. For the discussion on Dobrovolsky

(1999)'s findings on Chuvash, see section 5.3.1.2.

Lehiste *et al*. (2005) conducted an acoustic analysis of word-level stress in Eastern Mari. The study mainly focused on disyllabic words, but monosyllabic words, trisyllabic words, and four-syllable words were also recorded for acoustic analysis. Disyllabic words of the shape [CV.CV], [CVC.CV], [CV.CVC], and [CVC.CVC] were used to test the acoustic realization of stress. Additionally, [Cə.CV] words were also included in the experiment. In their corpus, there is no schwa in word-final position. Eight native speakers were recorded.

It was found that the phonetic correlates of stress include duration, which is a reliable cue; heightened F0, which is an auxiliary cue; and relatively optimal vowel quality, i.e. lack of vowel reduction. However, Lehiste *et al*. (2005: 64) note that "stress position appears not to be fixed with reference to a given syllable within a word." For example, in the set of disyllabic words, there were 29 words where the speakers stressed the first syllable, 13 words with stress on the second syllable, and for the remaining 16 words, different speakers positioned stress differently. For [Cə.CV] words in phrase-final position, 26 tokens had initial stress, whereas 22 tokens had final stress. For [Cə.CV] words in sentence-final position, 26 tokens had initial stress while 19 tokens had final stress.

Position		First syllable stressed							
		N	/ə/	V2	V1/V2	N	/ə/	V2	V1/V2
PF	x̄	26	99	126	0.78	54	113	138	0.82
	s.d.		18	9			21	21	
SF	x̄	26	102	117	0.87	52	107	128	0.84
	s.d.		16	14					
Overall average	x̄	52	101	122	0.83	106	110	133	0.83
	s.d.		17	12			19	21	
Position		Second syllable stressed							
		N	/ə/	V2	V1/V2	N	/ə/	V2	V1/V2
PF	x̄	22	46	170	0.27	18	78	202	0.39
	s.d.		10	17			14	17	
SF	x̄	19	45	169	0.27	19	73	192	0.38
	s.d.		9	22			18	23	
Overall average	x̄	41	46	170	0.27	37	76	197	0.39
	s.d.		10	20			16	20	

Table 5.4: Vowel durations (ms) and V1/V2 duration ratios in disyllabic CV.CV words
(table from Lehiste *et al*. 2005: 40).

Lehiste *et al*. (2005) further noted that schwa can be stressed – both when all vowels in the word are central vowels, and when the word also contains unstressed full vowels. When /ə/ bears stress, it is longer than unstressed /ə/ in the same position within a word, but shorter than a stressed full vowel in the same position.

What Lehiste *et al*. (2005)'s study suggests is that stress in Eastern Mari is highly lexicalized. Moreover, it shows that individual speakers stressed target words in different ways (see Table 5A in their study). So, stress assignment is also individualized. Given these two observations, one could conclude that stress assignment in Eastern Mari is not synchronically active, and lexicalized.

5.3.2.4 Distinctions between central vowels

Some languages are reported to make distinctions between central vowels for stress purposes. The theoretical importance of such cases will be reviewed below. First, the cases

themselves will be summarized.

- *Kobon*

Kenstowicz (1997), based on Davies (1981)'s data, claims that [ə] is more sonorous than [ɨ] in Kobon. However, the evidence comes from one word: [gɨsə́gɨsə́] 'to tap'. Davies (1981: 225) notes that "[t]here are very few four-syllable words. All of them are ideophones and are completely or partially reduplicated forms. Such words carry two stress placements of equal intensity on the first and third syllables or, if the vowels of these syllables are weak, on the second and fourth syllables." Davies (1981) classifies both [ə] and [ɨ] as 'weak vowels'. Davies (1981: 225)'s description, then, seems to imply that words of the shape /CəCɨCəCɨ/ would also have second and fourth syllable stress, i.e. [CəCɨ́CəCɨ́], not the sonority-driven *[Cə́CɨCə́Cɨ]. It is also important to note that Davies (1981: 225) emphasized the uncertainty of the description: "Further research is necessary before the rules for the placement of stress can be stated comprehensively. The following remarks are made tentatively pending such further study."

- *Ma Manda*

For Ma Manda, Pennington (2013) reports that [ə] is more sonorous than [ɨ]. However, similar to Kenstowicz (1997)'s analysis of Kobon, only one form is provided to support the sonority hierarchy: [qɨdə́] 'greens'. That is, the default initial stress avoids the high central vowel [ɨ] and lands on [ə] instead. Pennington (2013: 80) mentions that "the presence of the short barred-i vowel has led to a great deal of confusion (on my part) as well." Moreover, Pennington (2013: 83) further notes that [l]ikewise in Ma Manda, a

stressed word-initial barred-i vowel is still shorter (by up to 50ms) than a following

unstressed vowel, and a word-final unstressed vowel tends to be longer than preceding

stressed vowels." As mentioned in Pennington's work, there is no convergence of the

prototypical indicators of stress in Ma Manda. So, like Kobon, the distinction between [ɨ]

and [ə] is somewhat unreliable and needs further investigation.

• *Avam Nganasan*

Avam Nganasan (Vaysman 2009) contradicts the sonority hierarchy proposed by de Lacy

(2002): Vaysman (2009) argues that [ɨ] is more sonorous than [ə]. The evidence comes

from the situation where the antepenult has [ɨ], the penult contains [ə], and the penult is

foot-initial. In such a case, there is a free variation: primary stress can either be assigned to

the antepenultimate or penultimate syllable. Examples are given in (28).

(28)   Free variation in Nganasan stress

      (bɨnɨ)-(^{n}tə́nɨ) ~ (bɨnɨ́)-(^{n}tənɨ)   'rope (Loc.)'

      (ɲìnɨ)-(^{n}tə́nu) ~ (ɲinɨ́)-(^{n}tənu) 'brother (Loc.)'

      (bɨðɨ)-(tə́nɨ) ~ (bɨðɨ́)-(tənɨ)   'water (Loc.)'

      (kòlɨ)-(tə́nu) ~ (kolɨ́)-(tənu)   'fish (Loc.)'

Vaysman (2009) argues that such variation results from two factors: vowel sonority and

foot structure. When stress falls on the antepenult, it is the vowel sonority which determines

the optimal output. Since [ɨ] is more sonorous than [ə], stress avoids the penultimate [ə]

and moves to the antepenultimate [ɨ], as in (bɨnɨ́)-(^{n}tənɨ) 'rope (Loc.)'. As discussed in

section 5.2.3, consonant gradation does not provide evidence for Nganasan stress because it shows a mismatch between foot structure and stress placement.

• *Theoretical significance*

The theoretical significance of languages with more than one central vowel relates to which has a mora. So far, I have only discussed languages that have one central vowel, and called it 'schwa'. How do moras relate to multiple central vowels?

It is quite possible for all central vowels in a language to bear moras: e.g. [ə$^\mu$ ɨ$^\mu$]. In principle, it could be possible for one central vowel to bear a mora while another does not: i.e. either [° ɨ$^\mu$] or [ə$^\mu$ ɨ]. In such cases, stress would avoid the non-moraic vowel only. If the impressionistic descriptions are accurate, Kobon and Ma Manda would have the [ə$^\mu$ ɨ] inventory, while Avam Nganasan would have the [° ɨ$^\mu$] inventory.

However, it could also be the case that there are implicational relations between central vowels in terms of which one must bear a mora. For example, it is possible that if [ɨ] is moraic, then [ə] is moraic, too.

The rarity and uncertainty of languages with contrastive central vowels that interact with stress means that it is currently impossible to tell which path is correct. Hopefully, thorough investigations of one of the languages above will illuminate this issue in the future.

5.3.2.5 Interim summary

In summary, many descriptions lack corroborating phonetic and phonological evidence for their impressionistic descriptions of stress. It is therefore difficult to determine which type of schwa system they belong to. As shown for Piuma Paiwan in chapter 3, vowel duration

not only contributes to moraic content, but also results from other external factors, including closed syllable shortening, PrWd-final lengthening, and Frame 1 penult lengthening. Without a full duration model to account for each factor, it is hard to evaluate the moraic content of the target language. More systematic phonetic studies are required in the future.

5.4 Factorial typology

The previous chapters and sections have presented the core ideas of the present theory, illustrated its action in particular cases, and examined how it applies to reported cases of sonority-driven stress. However, a significant remaining question is what the theory predicts, typologically speaking: what are the range of phonological systems that can be generated using the theory?

The challenge with such a question in Optimality Theory is that the answer depends on what the other constraints in CON are. As just one example, the constraint $*\mu/\partial$ will interact with many constraints, such as those that regulate syllable nuclei form and content, syllable onset and coda form and content, and – as shown in previous chapters – other prosodic constraints. It will also interact with faithfulness constraints, potentially causing vowel reduction, or even schwa alteration.

Considering all potentially relevant constraints is a mammoth and currently a computational impractical task. So, in this section, a small set of constraints were chosen, and the possible grammars that they generate were examined. This very limited constraint system consisted of $*\mu/\partial$, HEADEDNESS-σ, constraints on foot alignment (ALLFTL, ALLFTR), and constraints on foot size (FTBIN) and foot headedness (TROCHEE/IAMB).

Even with these few constraints (and reasonable restrictions on GEN), 34,944 rankings were generated. Of these rankings, there were 86 distinct languages, where two rankings are the same 'language' if they produce the same input→output mappings (of the specific inputs examined here). These groups are discussed below in detail with the goal of identifying the predictions the theory makes about language types.

It should be noted that the factorial typology here does not consider unfaithfulness with respect to vowel length, as in Piuma Paiwan. That is, the moraic quantiy schwa is limited to be non-moraic and monomoraic, not bimoraic. If manipulation of length is factored into the current typology, systems would be generated where stress moves away from the default position if it contains a schwa, regardless of whether the non-default position contains schwa. This is the case in Piuma Paiwan: CV(CV́CV), CVCə(CV́ː), and CVCə(Cə́ː). Crucially, the moraic quantity of the final syllable can be changed to be be bimoraic. Computationally, the faithfulness constraint IDENT-LENGTH plays an impoartant role in such system. With the constraints limited as above, this system cannot exist without modification of moraic structure. See section 5.4.2 for more discussion.

Section 5.4.1 identifies the assumptions of this section: the constraints, the inputs, and the output candidates. As will be seen in sections 5.4.2 and 5.4.3, two main types of stress system are generated: apparent sonority-sensitive systems and sonority-insensitive systems. Of the sonority-sensitive systems, there are many subtypes depending on what [ə] does in different environments. Section 5.4.4 focuses on the varieties of 'foot shrinking' – where feet surface as monosyllabic in order to avoid non-moraic schwas.

5.4.1 Constraints and inputs

Eight constraints are considered in the typology, including moraicity constraints (*μ/ə and

HDσ), foot form constraints (FTBIN-μ and FTBIN-σ), foot type constraints (TROCHEE and

IAMB), and foot alignment constraints (ALLFTL and ALLFTR). Constraints definition are

given in (29).

(29) Constraints used in the typology

   a. Moraicity constraints

      *μ/ə: Incur a violation for every schwa that bears a mora.

      HDσ: Incur a violation for any σ that does not dominate a μ.

   b. Foot form constraints

      FTBIN-μ: Incur a violation for any foot that does not contain two moras.

      FTBIN-σ: Incur a violation for any foot that does not contain two syllables.

   c. Foot type constraints

      TROCHEE: Incur a violation if the leftmost footed syllable is not stressed.

      IAMB: Incur a violation if the rightmost footed syllable is not stressed.

   d. Foot alignment constraints

      ALLFTL: Incur a violation if the left edge of every foot is not aligned with the

      left edge of a PrWd.

      ALLFTR: Incur a violation if the right edge of every foot is not aligned with the

      right edge of a PrWd.

The inputs considered are as follows, where 'C' is some consonant, 'V' is some non-schwa vowel and 'ə' is schwa. No further distinctions were made since the goal was to focus on the behavior of schwa.

(30)   Inputs for the typology

   a. /CVCVCV/

   b. /CVCVCə/

   c. /CVCəCV/

   d. /CəCVCV/

   e. /CVCəCə/

   f. /CəCVCə/

   g. /CəCəCV/

   h. /CəCəCə/

Many restrictions were placed on the output candidates considered. No unfaithful candidates (i.e. with epenthesis or deletion or neutralization) were considered. The lack of such candidates was designed to allow focus on the metrical systems, and not the interaction of metrical structure and neutralization. The implications of the present theory for neutralization and other feature-change operations is certainly an interesting and potentially very fruitful area to explore, but it would take us too far afield here.

The output candidates considered had restrictions on their foot form. Every candidate was required to have one (and only one) foot. Feet were either mono- or di-syllabic; no three syllable or larger feet were considered (following, e.g., Hayes 1995).

Feet were required to have heads except when there were no moras; in effect, the only headless feet were (C°C°) and (C°) (where ° is a non-moraic schwa). Feet could be trochaic (left-headed) or iambic (right-headed). All of the candidates and their violation profiles can be found in Appendix D. Here, as an illustration, the following candidates form the complete candidate set for the input /CVCəCə/. Here and below, 'ə' is moraic schwa ([əᵘ]), and 'ᵊ' is non-moraic schwa.

(31)   Candidates for /CVCəCə/

(CV́)C°C°

(CV́)C°Cə

(CV́)CəC°

(CV́)CəCə

(CV́C°)C°

(CV́C°)Cə

(CVCə́)C°

(CV́Cə)C°

(CVCə́)Cə

(CV́Cə)Cə

CV(C°)C°

CV(C°)Cə

CV(C°C°)

CV(C°Cə́)

CV(Cə́)C°

CV(Cə́)Cə

CV(Cə́Cᵊ)

CV(CəCə́)

CV(Cə́Cə)

CVCᵊ(Cᵊ)

CVCᵊ(Cə́)

CVCə(Cᵊ)

CVCə(Cə́)

With 8 constraints, the number of possible rankings is 8! (40,320). However, a subset of rankings was excluded, that is, those where the winner for /CVCVCV/ had a monosyllabic foot: [(CV́)CVCV] or [CVCV(CV́)]. Such winners occurred when TROCHEE and IAMB outranked FTBIN as (CV́) is both trochaic and iambic. Since such languages presumably do not occur, they were excluded from consideration as irrelevant here. As a result, there were 34,944 rankings in total. The rankings create 86 distinct groups. For the full results with constraint violations, input-output mappings, and constraint rankings, see Appendix D. The grammars and groups were calculated using custom-made software.

Among the 86 groups, 74 groups display an apparent sonority-sensitive stress system, whereas 12 groups have regular stress assignment.[3] The reason why the system is termed 'apparent' is that there is no constraint referring to vowel sonority, but the surface

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[3] If language typology straightforwardly reflects factorial typology, the percentages given here might suggest that around 86% of languages (though not grammars) with contrastive schwa should have sonority-driven stress (i.e. stress would avoid schwa). However, only eight constraints were employed to generate the typology; if all constraints are taken into account, the relative percentages would almost certainly change. Also, there are many non-linguistic factors which affect language typology, other than just cognitive ones (e.g. de Lacy 2014).

pattern looks like it has sonority-driven stress. In these cases, stress does not fall on the default position if it contains a schwa.

As argued in previous chapters, stress avoids schwa in the default position in such languages because the schwa is non-moraic.

Systems	Total number of groups
Sonority-sensitive stress	74
Sonority-insensitive stress	12

Table 5.5: Results from the typology.

5.4.2 Apparent sonority-sensitive stress

In principle, there are two distinct types of sonority-driven stress system as determined by whether stress avoids a default schwa. In Type A, stress will fall on the default position unless (a) the default contains schwa *and* (b) stress can fall on an available non-schwa: e.g. (CV́CV)CV, (C°CV́)CV, (Cə́Cə)Cə. In Type B, stress will fall on the default position unless the default contains schwa, in which case it will appear on a non-default syllable *regardless* of whether it contains schwa: e.g. (CV́CV)CV, (C°CV́)CV, (C°Cə́)Cə. The difference between the two systems just cited lies in stress assignment on the /CəCəCə/ form: Type (A) has stress on the default position while Type (B) moves stress away.

Interestingly, the constraints presented above cannot generate Type B patterns: no grammar produced a Type B system. Of course, Piuma Paiwan apparently has just such a system (see chapter 3): in previous descriptions, stress moves away from the default position if it contains a schwa, regardless of whether the non-default contains schwa: e.g. CV(CV́CV), CV(CəCV́), CV(CəCə́). However, it was found in chapter 3 that Piuma Paiwan does not actually have this system because the moraic quantity of the final syllable

varies: i.e. the outputs are actually CV(CV́CV), CVCᵊ(CV́:), CVCᵊ(Cə́:). With the constraints limited as above, then, Type B systems cannot exist without modification of moraic structure, as in Piuma Paiwan.

Of the Type A patterns, there are two subtypes. In Type A1, stress will fall on schwa when there is no alternative: e.g. (CV́CV)CV, (CᵊCV́)CV, (Cə́Cə)Cə. In Type A2, stress will never fall on schwa: e.g. (CV́CV)CV, (CəCV́)CV, (CᵊCᵊ)Cə. In A2 types, /CəCəCə/ inputs emerge without foot heads.

There are potentially many further subtypes of both A1 and A2. Languages could vary as to whether foot non-heads may contain non-moraic schwa: e.g. whether /CəCəCə/ becomes [(Cə́)Cᵊ.Cᵊ] vs. [(Cə́.Cᵊ)Cᵊ]. They also differ as to whether foot non-head schwas are moraic or non-moraic: e.g. [(Cə́.Cᵊ)Cᵊ] vs. [(Cə́.Cə).Cᵊ]. They finally differ as to whether unfooted schwas are moraic or not: e.g. [(Cə́.Cə)Cᵊ] vs [(Cə́.Cə)Cə].

Strikingly, of the 12 possible combinations, only 4 can be generated with the current constraints. Table 5.6 summarizes the findings.

Essentially, there are strong implicational relationships for /CəCəCə/ inputs. Of the A1 types (where schwa can be stressed), unfooted schwas *must* be non-moraic, while footed non-head schwas can be either moraic or non-moraic, i.e. possible winners that are trochaic and left-aligned are (Cə́.Cᵊ)Cᵊ, (Cə́.Cə)Cᵊ, and (Cə́)Cᵊ.Cᵊ, and no others. Of the A2 types, only [(CᵊCᵊ)Cᵊ] can ever win. These are strong and interesting implications. They mean that if a language has sonority-driven stress, unfooted schwas must be non-moraic, with all the attendant phonological and phonetic consequences, as detailed in previous chapters. If /CəCəCə/ outputs have a stressed schwa, though, there is no predicting whether the non-head footed schwa will be moraic or not.

Table 5.6 focuses on systems where the winners all have trochaic feet at the left edge of the PrWd. These systems will be the focus of the rest of this section. Similar results hold of systems with right-aligned trochees, and iambs at either edge.

[ə́]?	Non-head	Unfooted	Winner	Group	Type
Yes	[ə]	[ə]	(Cə́.Cə)Cə	*Not attested*	
		[ᵊ]	(Cə́.Cə)Cᵊ	26, 27, 28 29	A1a
	[ᵊ]	[ə]	(Cə́.Cᵊ)Cə	*Not attested*	
		[ᵊ]	(Cə́.Cᵊ)Cᵊ	8, 9, 21, 23, 30, 31, 32, 33, 34, 35, 36, 37, 50, 52, 54, 56, 58, 59, 61, 63, 65, 67	A1b
	None	[ə ə]	(Cə́)Cə.Cə	*Not attested*	
		[ə ᵊ]	(Cə́)Cə.Cᵊ	*Not attested*	
		[ᵊ ə]	(Cə́)Cᵊ.Cə	*Not attested*	
		[ᵊ ᵊ]	(Cə́)Cᵊ.Cᵊ	10, 22, 51, 53, 55, 57, 60, 62, 64, 66	A1c
No	[ə]	[ə]	(Cə.Cə)Cə	*Not attested*	
		[ᵊ]	(Cə.Cə)Cᵊ	*Not attested*	
	[ᵊ]	[ə]	(Cᵊ.Cᵊ)Cə	*Not attested*	
		[ᵊ]	(Cᵊ.Cᵊ)Cᵊ	6, 7, 11, 12, 19, 20, 24, 25, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85	A2

Table 5.6: The fate of /CəCəCə/ in systems with trochaic left-aligned feet.

Both Type A and Type B share the basic constraint ranking: *μ/ə » HDσ. This means that for the two types, non-moraic schwa must be allowed in at least some prosodic positions (due to the fact that the other constraints cannot effectively block non-moraic schwa in all positions). However, it does not mean that if a language has non-moraic schwa, it then has sonority-driven stress, as will be shown in section 5.4.3. It is also impossible for a language to have sonority-driven stress with only moraic schwa.

(32) Basic apparent sonority-driven stress ranking

/CəCVCV/	*μ/ə	HDσ
☞ a. Cᵊ(CV́.CV)		*
b. (Cə́.CV)CV	*!	

Let us focus on the constraint ranking for Type A2 first. All 38 groups have the following constraint ranking in common: *μ/ə » HDσ, FTBINμ, TROCHEE, IAMB. This ranking restricts schwa to be non-moraic everywhere, as *μ/ə outranks constraints that can require schwa to be moraic. In (33), candidates (33b), (33c), and (33d) all fatally violate *μ/ə because they have at least one moraic schwa. The optimal candidate is (33a), even though it violates HDσ, FTBINμ, TROCHEE, and IAMB. Note that candidates with a monosyllabic foot such as [(Cᵊ)Cᵊ.Cᵊ] have the same violation profile as (33a). The purpose here is to show why schwa surfaces as non-moriac; for reasons why a foot shrinks, see section 5.4.4.

(33) Shared constraint ranking for Type A2

/CəCəCə/	*μ/ə	HDσ	FTBINμ	TROCHEE	IAMB
☞ a. (Cᵊ.Cᵊ)Cᵊ		***	*	*	*
b. (Cə́.Cə)Cə	*!**				*
c. (Cə́.Cə)Cᵊ	*!*	*			*
d. (Cə́.Cᵊ)Cᵊ	*!	**	*		*

Recall that Type A1 allows a mixed combination of different kinds of schwa. So, the constraint *μ/ə has to be outranked by one of the constraints that can force schwa to be moraic. As can be seen below, this is achieved by ranking either FTBINμ, TROCHEE, or IAMB over *μ/ə. Note that ranking HDσ over *μ/ə does not generate sonority-driven stress systems, as it forces all the schwas in the input to be moraic (see section 5.4.3).

For Type A1a, the output of /CəCəCə/ is [(Cə́.Cə)Cᵊ]: schwa is moraic in the head and non-head position of the foot, but non-moraic outside the foot. This outcome is due to FTBINμ forcing the first two schwas in the foot to be moraic, as shown in (34). Both candidates (34b) and (34c) fatally violate FTBINμ because schwa in the non-head position is non-moraic. Although candidate (34d) satisfies FTBINμ, the unfooted schwa is moraic. So, it incurs more violations of *μ/ə than that of candidate (34a).

(34)　　Type A1a: Group #26

/CəCəCə/	FTBINμ	*μ/ə	HDσ
☞　a. (Cə́.Cə)Cᵊ		**	*
b. (Cə́.Cᵊ)Cə	*!	*	*
c. (Cᵊ.Cᵊ)Cᵊ	*!		***
d. (Cə́.Cə)Cə		***!	

For Type A1b, /CəCəCə/ has the output [(Cə́.Cᵊ)Cᵊ]. Schwa is moraic in the head position of the foot, but non-moraic elsewhere. For Type A1c, the output for /CəCəCə/ words is [(Cə́)Cᵊ.Cᵊ]. Crucially, it differs from the output of Type A1b in that there is no schwa in the non-head position of the foot: it has a monosyllabic foot and two unfooted syllables. Nevertheless, Type A1b and Type A1c share the same basic ranking: TROCHEE » *μ/ə » HDσ. So, the output has to satisfy TROCHEE or IAMB. Whether the output has a bisyllabic or monosyllabic foot is further determined by other constraints, as discussed below.

It is clear that output forms like [(Cᵊ.Cᵊ)Cᵊ] are eliminated by TROCHEE, as exemplified in (35c). Moreover, candidate (35c) is ruled out by ALLFTL because it is one syllable away from the left edge of the word. Essentially, either ALLFTR or FTBINσ must

outrank IAMB to block foot shrinking. So, candidate (35b) fatally violates ALLFTR and FTBINσ. The optimal output is (35a).

(35)   Type A1b: Group #50

/CəCəCə/	TROCHEE	*μ/ə	ALLFTL	ALLFTR	FTBINσ	IAMB
☞ a. (Cə́.Cə)Cə		*		*		*
b. (Cə́)Cə.Cə		*		**!	*!	
c. (Cə.Cə)Cə	*!			*		*
d. Cə(Cə́.Cə)		*	*!			*

In contrast, if IAMB outranks both ALLFTR and FTBINσ, the foot has to shrink to a monosyllable in order to satisfy IAMB. Candidate (36b) incurs a violation of IAMB because the foot is not iambic. For the emergent effect of foot type constraints, see discussion in section 5.4.4.

(36)   Type A1c: Group #51

/CəCəCə/	TROCHEE	*μ/ə	ALLFTL	IAMB	ALLFTR	FTBINσ
☞ a. (Cə́)Cə.Cə		*			**	*
b. (Cə́.Cə)Cə		*		*!	*	

In short, there are two main types of sonority-sensitive stress: Type A1 and Type A2. They all share the ranking *μ/ə » HDσ. To generate apparent sonority-sensitive stress, non-moraic schwa must be present in the output.

5.4.3 Sonority-insensitive stress

In the typology, 12 groups have sonority-insensitive stress: stress always falls on a fixed position in a word regardless of whether it contains schwa or not. For example, in Group #1, stress consistently falls on the initial syllable no matter where the schwa is. Three

languages of this type were found in the typology, as shown in Table 5.7. Like section 5.4.2,

I use groups with default left-aligned trochaic feet for discussion (i.e. [(CV́.CV)CV]).

[ə́]	Non-head	Unfooted	Winner	Group	Type
Yes	[ə]	[ə]	(Cə́.Cə)Cə	1, 3, 14, 16	C1
		[ᵊ]	(Cə́.Cə)Cᵊ	0, 2, 13, 15	C2
	[ᵊ]	[ə]	(Cə́.Cᵊ)Cə	*Not attested*	
		[ᵊ]	(Cə́.Cᵊ)Cᵊ	4, 5, 17, 18	C3
No	[ᵊ]	[ᵊ]	(Cᵊ.Cᵊ)Cᵊ	*Not attested*	

Table 5.7: Different types of sonority-insensitive stress.

For Type C1, the output for /CəCəCə/ words is [(Cə́.Cə)Cə]. The common ranking

shared by these four groups is HDσ » *μ/ə. This ranking ensures that schwa surfaces as

moraic in all environments in the output. For example, in the tableau below candidates

(37b) and (37c) contain non-moraic schwa, so they are eliminated by HDσ.

(37)   Type C1: Group #1

/CəCəCə/	HDσ	*μ/ə
☞ a. (Cə́.Cə)Cə		***
b. (Cə́.Cᵊ)Cə	*!	**
c. (Cə́.Cᵊ)Cᵊ	**!	*

Interestingly, non-moraic schwa is allowed in Type C2 and Type C3. For Type C2,

non-moraic schwa appears in unfooted position only. For Type C3, non-moraic schwa

appears in both unfooted position and the non-head syllable of the foot. This fact suggests

that *μ/ə should dominate HDσ in order for non-moraic schwa to surface in the output.

This turns out to be true in examining the common ranking of Type C2 and Type C3. Both

C2 and C3 have the same constraint ranking: *μ/ə » HDσ. However, crucially, one of the

foot alignment constraints (ALLFTL and ALLFTR) dominates the constraint *μ/ə. The consequence is that the position of the foot is fixed. The foot is strictly aligned with either the left or right edge of the word. As can be seen in (38), stress falls on the initial syllable (default stress position) even if it contains a schwa. Candidate (38b) is ruled out because the foot is not left-aligned. In short, Type C2 and Type C3 represent a disguised sonority-driven stress system, where foot alignment constraints block the avoidance of schwa.

(38)   Constraint ranking shared by Type C2 and Type C3

/CəCVCV/	ALLFTL	*μ/ə	HDσ
☞ a. (Cə́.CV)CV		*	
b. Cə(CV́.CV)	*!		*

As mentioned above, Type C2 differs from Type C3 in that schwa in the foot is always moraic. This is due to the fact that FTBINμ dominates *μ/ə. If a foot contains two schwas, both of them have to be moraic to satisfy FTBINμ. As shown in (39), a foot that has zero mora (39b) or one mora (39c) is ruled out by FTBINμ. Candidate (39d) is eliminated by *μ/ə since all the schwas are moraic.

(39)   Type C2: Group #0

/CəCəCə/	FTBINμ	*μ/ə	HDσ
☞ a. (Cə́.Cə)Cə		**	*
b. (Cə.Cə)Cə	*!		***
c. (Cə́.Cə)Cə	*!	*	**
d. (Cə́.Cə)Cə		***!	

In contrast to Type C2, FTBINμ is dominated by *μ/ə in Type C3. Moreover, one of the foot type constraints (TROCHEE and IAMB) outranks *μ/ə. So, the optimal output does not need to satisfy FTBINμ but needs to satisfy one of the foot type constraints.

Candidate (40b) violates TROCHEE because the foot is headless. Candidate (40c) incurs two violations of *μ/ə because the two schwas in the foot are moraic. Candidate (40a) is the winning output, even though it violates FTBINμ.

(40)   Type C3: Group #4

/CəCəCə/	TROCHEE	*μ/ə	HDσ	FTBINμ
☞ a. (Cə́.Cᵊ)Cᵊ		*	**	*
b. (Cᵊ.Cᵊ)Cᵊ	*!		***	*
c. (Cə́.Cə)Cᵊ		**!	*	

In sum, the ranking HDσ » *μ/ə results in a genuine sonority-insensitive stress system, where all the schwas are moraic on the surface. Interestingly, the reverse ranking *μ/ə » HDσ can also generate a sonority-insensitive stress system, but this is under the condition that one of the foot alignment constraints must outrank *μ/ə. Finally, the ranking of FTBINμ and foot type constraints plays a crucial role in determining the moraic content of the foot.

5.4.4 Foot shrinking

In some sonority-sensitive stress systems, feet react to non-moraic schwa by shrinking. For example, Group 9 has default left-aligned iambic feet: [(CV.CV́).CV]. However, /CVCəCV/ emerges with a monosyllabic foot: [(CV́)Cᵊ.CV]. In the following discussion, I use the term 'foot shrinking' to refer to the process where the winner has a monosyllabic foot.

Table 5.8 presents the distribution of foot shrinking. We see that none of the A1a groups have shrinking, while all the A1c types shrink. A1b and A2 have roughly equal

numbers of languages with shrinking. This distribution raises the question of why there are at least some implicational relationships in foot shrinking, why shrinking occurs, and how it relates to non-moraic schwas. The following sections will address these issues in turn.

Type	Foot shrinking	Group #
A1a	Yes	*None*
	No	26, 27, 28, 29
A1b	Yes	8, 9, 21, 23, 52, 54, 56, 58, 59, 61, 63, 65, 67
	No	30, 31, 32, 33, 34, 35, 36, 37, 50
A1c	Yes	10, 22, 51, 53, 55, 57, 60, 62, 64, 66
	No	*None*
A2	Yes	11, 12, 24, 25, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85
	No	6, 7, 19, 20, 25, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49

Table 5.8: Result for foot shrinking.

5.4.4.1 Motivation

In all cases, the motivation for foot shrinking is to satisfy TROCHEE and/or IAMB, either directly or emergently. Take Group 9 for illustration. This group has the following mappings:

(41)   Group 9 mappings

/CVCVCV/   →   (CVCV́)CV

/CVCVCə/   →   (CVCV́)Cᵊ

/CVCəCV/   →   (CV́)CᵊCV

/CəCVCV/ → (CᵊCV́)CV

/CVCəCə/ → (CV́)CᵊCᵊ

/CəCVCə/ → (CᵊCV́)Cᵊ

/CəCəCV/ → (CᵊCə́)CV

/CəCəCə/ → (CᵊCə́)Cᵊ

In Group 9, foot shrinking occurs in only two mappings: /CVCəCV/ and /CVCəCə/. It occurs because in the winning forms the rightmost syllable of the foot cannot be stressed (i.e. when IAMB would be violated): e.g. /CVCəCV/ → [(CV́)Cᵊ.CV] because in *[(CV́Cᵊ)CV] the leftmost syllable is stressed.

The two constraints that prefer binarity are FTBINμ and FTBINσ. As shown in (42), IAMB and *μ/ə both have to outrank FTBINμ and FTBINσ, as the optimal candidate (42a) is not binary at the syllabic and moraic levels. Interestingly, IAMB and *μ/ə also have to outrank ALLFTR, as the right edge of the monosyllabic foot in (42a) is two syllables away from the right edge of the word, unlike the other forms.

(42)　Motivation for foot shrinking

/CVCəCV/	IAMB	*μ/ə	FTBINμ	FTBINσ	ALLFTR	HDσ
☞ a. (CV́)Cᵊ.CV			*	*	**	*
b. (CV́.Cᵊ)CV	*!		*		*	*
c. (CV.Cə́)CV		*!			*	
d. (CV́.Cə)CV	*!	*			*	

5.4.4.2 Reactions to TROCHEE/IAMB

Exactly how a grammar will react to TROCHEE and IAMB depends on the details of its ranking. However, there are certain generalizations that can be made about the rankings involved.

Crucially, shrinking will only occur when the grammar allows non-moraic schwa. However, it is not the case that if a grammar allows non-moraic schwa, foot shrinking has to happen (e.g. Types A1a and A1b; see Table 5.6). The foot form constraints (FTBINµ and FTBINσ) and foot alignment constraints (ALLFTR and ALLFTL) could block foot shrinking given the right ranking.

In general, the foot shrinks when there is a non-moraic schwa in the defualt stress position. For example, Group 63 has default left-aligned iambic feet: [(CV.CV́)CV]. Inputs with a schwa in the penult, such as /CVCəCV/ and /CVCəCə/, surface with a monosyllabic foot: [(CV́)Cᵊ.CV] and [(CV́)Cᵊ.Cᵊ]. As the tableaux below show, foot shrinking in language 25380 is motivated by the need to have an iambic foot at the left edge of the PrWd *and* to maximize non-moraic schwas. When there is a schwa in the second syllable, there is an inevitable conflict which is resolved in this language by shrinking the foot so that it can be left-aligned, if not binary.

(43)   Group #63, language 25380: /CVCəCV/ – Shrinking

/CVCəCV/	IAMB	*ə/µ	FTBINµ	ALLFTL	FTBINσ	TROCHEE	HDσ
☞ a. (CV́)Cᵊ.CV			*		*		*
b. (CV́.Cᵊ)CV	*!		*				*
c. (CV.Cə́)CV		*!				*	
d. (CV́.Cə)CV	*!	*					
e. CV(Cᵊ.CV́)			*	*!		*	*

(44)   Group #63, language 25380: /CVCəCə/ – Shrinking

/CVCəCə/	IAMB	*µ/ə	FTBINµ	ALLFTL	FTBINσ	TROCHEE	HDσ
☞ a. (CV́)C^ə.C^ə			*		*		**
b. (CV́.C^ə)C^ə	*!		*				**
c. (CV.Cə́)C^ə		*!				*	*
d. (CV́.Cə)C^ə	*!	*					*
e. CV(C^ə.Cə́)		*!	*	*		*	*
f. CV(Cə.Cə́)				*!		*	

However, it is not always the case that a non-moraic schwa in the default position causes foot shrinking. When the input has two schwas in the first two syllables, such as /CəCəCV/, the foot does not shrink. Instead, it maintains its binarity and moves one syllable away to the right edge of the word: [C^ə(C^ə.CV́)].

(45)   Group #63 /CəCəCV/ – No shrinking

/CəCəCV/	IAMB	*µ/ə	FTBINµ	ALLFTL	FTBINσ	ALLFTR	HDσ
☞ a. C^ə(C^ə.CV́)			*	*			**
b. (Cə́)C^ə.CV		*!	*		*	**	*
c. (C^ə.Cə́)CV		*!	*			*	*
d. (C^ə.C^ə)CV	*!		*			*	**

The reason that the foot does not shrink in /CəCəCV/ is due to the vowels involved in the foot. The foot has to satisfy the undominated constraint IAMB, so any candidate that violates IAMB is eliminated, like (45d). However, there is a subtle distinction between foot forms that satisfy IAMB. As schwa is required to be non-moraic, any iambic foot that has moraic schwa is also eliminated. So, even though candidates (45b) and (45c) have no

violation of IAMB, they fatally violate *μ/ə. As a consequence, the foot does not shrink, but rather moves to the right edge of the word.

All 23 rankings which comprise Group #63 share these rankings: (a) IAMB » *μ/ə » all other constraints, (b) FTBINμ » all constraints except (optionally) HDσ, (c) ALLFTL » ALLFTR, FTBINσ, TROCHEE. As seen in the tableaux above, the ranking of IAMB and *μ/ə is crucial in eliminating those competitors that would place stress on a peninitial schwa. The ranking of ALLFTL » FTBINσ is crucial in eliminating candidates that would move the foot away from the left edge instead of shrinking it.

Group 50 presents another interesting case. It has default left-aligned trochaic feet: [(CV́.CV)CV]. When there is a non-moraic schwa in the initial syllable, the foot does not shrink; instead, it has a trochee alighed with the right edge of the word: [Cə.(CV́.CV)].

(46)   Group #50

/CəCVCV/	TROCHEE	*μ/ə	FTBINμ	FTBINσ	HDσ	ALLFTL	ALLFTR
☞ a. Cə(CV́.CV)					*	*	
b. Cə(CV́)CV			*!	*!	*	*	*
c. (Cə́.CV)CV		*!					*
d. (Cə.CV́)CV	*!		*		*		*

Crucially, two options are available to avoid having an initial trochee, as can be seen in (46a) and (46b). Both candidates satisfy TROCHEE and *μ/ə. However, candidate (46b) is ruled out because it fatally violates the foot form constraints FTBINμ and FTBINσ. So, there is no need for the foot to shrink in this situation.

Group 66 shows that both foot type constraints are responsible for foot shrinking. The language is default iambic: [(CV.CV́)CV]. Like Group 63, shrinking occurs in [(CV́)CᵊCV] because IAMB demands it. However, shrinking also occurs in /CVCəCə/, /CəCVCə/, /CəCəCV/, and /CəCəCə/. The is due to the emergent effect of TROCHEE. Here I use /CəCVCə/ for demonstration.

(47)   Type A3: Group #66

/CəCVCə/	IAMB	*μ/ə	FTBINμ	TROCHEE
☞ a. Cᵊ(CV́)Cᵊ			*	
b. (Cᵊ.CV́)Cᵊ			*	*!

Both candidates have a perfect iambic foot, and there is no moraic shcwa in the output. However, due to the effect of TROCHEE, the foot has to shrink in order to satisfy both IAMB and TROCHEE at the same time. In other words, the foot that best satisfies both IAMB and TROCHEE is monosyllabic.

Finally, some groups in Type A2 show foot shrinking. Recall that Type A2 has the common constraint ranking: *μ/ə » HDσ, FTBINμ, TROCHEE, IAMB. Even though both foot type constraints are dominated by *μ/ə, they still result in foot shrinking. Feet in Group 69 are iambic by default, but /CVCəCV/ surfaces as [(CV́)Cᵊ.CV].

(48)   Type A2: Group #69

/CVCəCV/	*μ/ə	FTBINμ	IAMB	TROCHEE
☞ a. (CV́)Cᵊ.CV		*		
b. (CV́.Cᵊ)CV		*	*!	
c. (CV.Cə́)CV	*!			*
d. (CV́.Cə)CV	*!		*	

In summary, the motivation for foot shrinking is to satisfy TROCHEE and/or IAMB, either directly or emergently. It takes place when (a) there is a non-moraic vowel in the default stress postion, (b) no moraic schwa is permitted in the foot, and (c) no environment is available to satisfy the requriement on foot binarity.

5.4.4.3 Blocking foot shrinking

There are some groups in which feet never shrink. As shown above, FTBINμ, FTBINσ, and ALLFTR/ALLFTR have the potential to block foot shrinking. This is evident in all groups in Type A1a, and some groups in Type A1b and Type A2. All the groups used for illustration below have default left-aligned iambic feet.

Constraints that require feet to be binary, such as FTBINμ and FTBINσ, can prevent foot shrinking, if they outrank *μ/ə. For Group 28, FTBINμ outranks *μ/ə. Since FTBINμ requires a foot to have two moras, it will force schwa to be moraic if necessary. For Group 28, the output of /CVCəCV/ is [(CV.Cə́)CV]. Although allowing a moraic schwa violates *μ/ə, the output satisfies FTBINμ. Candidate (49b) is ruled out because the foot is mono-moraic.

(49)   Type A1a: Group #28

/CVCəCV/	FTBINμ	*μ/ə	HDσ
☞ a. (CV.Cə́)CV		*	
b. (CV́)Cᵊ.CV	*!		*

Interestingly, the output of /CəCəCV/ is [Cᵊ(Cə.CV́)], not *[(Cə.Cə́)CV]. This is because the foot contains two moraic schwas, so its second violation of *μ/ə is fatal. So, the best

option is to have only one moraic schwa in the foot and satisfy FTBINμ at the same time.

As a result, candidate (50b) is eliminated by FTBINμ.

(50)   Type A1a: Group #28

/CəCəCV/	FTBINμ	*μ/ə	HDσ
☞ a. Cᵊ(Cə.CV́)		*	*
b. (Cᵊ.Cə́)CV	*!	*	*
c. (Cə.Cə́)CV		**!	

Similarly, FTBINσ can ban foot shrinking. For Group 34, FTBINσ outranks *μ/ə. The output of /CVCəCV/ is [CV(Cᵊ.CV́)], not *[(CV́)Cᵊ.CV]. As FTBINσ requires a foot to be binary at the syllabic level, candidate (51b) with a monosyllabic foot is ruled out. Candidate (51c) has a moraic schwa, so it is eliminated by *μ/ə.

(51)   Type A2: Group #34

/CVCəCV/	FTBINσ	*μ/ə	HDσ
☞ a. CV(Cᵊ.CV́)			*
b. (CV́)Cᵊ.CV	*!		*
c. (CV.Cə́)CV		*!	

Finally, ALLFTL and ALLFTR can also gang up to do the same. Group 39 (ranking 27527) has non-moraic schwa, and TROCHEE and IAMB outrank FTBINσ. However, ALLFTL and ALLFTR both outrank TROCHEE and IAMB, and that requires all feet to be binary. FTBINμ is not decisive in determining the optimal output. All candidates violate FTBINμ because none of the feet has two schwas. Candidate (52b) incurs two violations of ALLFTR because the foot is two syllables away from the right edge of the word. Candidate

(52c) violates ALLFTL once because the foot is one syllable away from the left edge of the word.

(52)   Type A2: Group #39 (ranking 27527)

/CVCəCV/	*μ/ə	FTBINμ	ALLFTL	ALLFTR	IAMB	TROCHEE	FTBINσ
☞ a. (CV́.Cə)CV		*		*	*		
b. (CV́)Cə.CV		*		**!			*
c. CV(Cə.CV́)		*	*!			*	

In sum, foot shrinking is prohibited when (a) FTBINμ and FTBINσ outrank *μ/ə, and (b) ALLFTL and ALLFTR outrank TROCHEE and IAMB.

5.4.5 Summary

This section has shown that without constraints referring to vowel sonority, one can generate two types of sonority-driven stress, with different combinations of moraic and non-moraic schwas. However, sonority-driven stress is not caused by a specific markedness constraint against stressed schwas. Instead, it is entirely due to the moraicity of schwa.

The preceding sections have also revealed an important point. Previous research has focused on stress and its relation to schwa. However, the present theory is about the *moraicity* of schwa, and stress repulsion as a side-effect of lack of moraicity. The present theory goes further in making predictions about possible configurations of moraic and non-moraic schwa *outside* the foot head – both in non-head position inside the foot and unfooted positions. It predicts that in any language with sonority-driven stress, unfooted schwas

must be non-moraic, while footed non-head schwas can be either moraic or non-moraic. In addition, it allows for three responses to a schwa in the non-head of a foot: either to let the schwa be moraic (A1a), non-moraic (A1b), or shrink the foot (A1c). Of all the systems imaginable, only a few of these combinations should be attested, as long as the constraint system considered here is on the right track.

This section has also delved into the particular subtype of system where feet in winners are monosyllabic due to the action of $*\mu/\text{ə}$ and other metrical constraints, notably IAMB and TROCHEE.

It remains to be seen whether all the predicted systems exist. At the very least, the present theory provides a place to start: for any future work on sonority-driven stress, it is clear that to identify where in the typology a language lies, it is crucial to not only measure the duration and quality of foot heads, but also those of non-head footed syllable heads, and unfooted syllable heads.

CHAPTER 6

CONCLUSION

This dissertation started with a proposal for an enriched moraic representation for schwa, repeated in (1). Crucially, I have proposed that non-moraic, monomoraic, and bimoraic schwas can co-exist in the same phonological system. The three kinds of schwa were argued to have distinct phonetic properties in their duration and vowel quality variance.
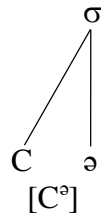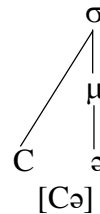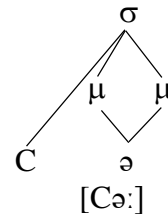
(1)   Syllables with schwa
        a. Minor syllable   b. Monomoraic schwa   c. Bimoraic schwa
        with nonmoraic schwa

Evidence for (1) was shown to come from my fieldwork and experiment on Piuma Paiwan, in which schwa can surface as stressed or unstressed, depending on the environment (see chapter 3). Stress in Piuma Paiwan avoids schwa in the default penultimate position: [kərí] 'small' cf. [káka] 'sibling'. Interestingly, stress moves away from a penultimate schwa when the final syllable also contains schwa: [ɬəʎə́t] 'lip'. I have shown that F0 provides clear evidence that stress avoids schwa in the penultimate position. However, such avoidance is actually a side-effect of schwa's prosodic status: schwa is usually non-moraic in Piuma Paiwan (e.g. [kᵊ(ríᵘᵘ)]). Furthermore, schwa is required to be monomoraic when in the non-head position of a foot (e.g. [(tíᵘ.dəᵘq)]), and bimoraic when

in the head syllable of a foot (e.g. [̩ʔ(ʎə́ᵘᵘt)]). The acoustic effects of the three schwa types were evident by their respective durations, with non-moraic shcwa around 50ms long, monomoraic schwa 70-80ms long, and bimoraic schwa around 135ms long. Moreover, non-moraic schwa showed greater vowel quality variation than moraic schwa.

This dissertation further proposed a condition on hierarchical locality, repeated here in (2).

(2)   Hierarchical Locality restriction on markedness constraints

If a markedness constraint mentions prosodic node *p*, it may mention nodes at *p-1* and *p-2*, but no nodes at other levels.

That is, markedness constraints are restricted in their internal structure. The formal effect of Hierarchical Locality is that there can be no constraints of the form $*HD_{Ft}/ə$, and the major empirical predicion is that stress is not sensitive to vowel sonority.

Evidence for (2) was shown to come from one of the clearest and most revealing cases of sonority-driven stress with distinctions among peripheral vowels: Gujarati (see chapter 4). Many descriptions report that the highly sonorous vowel [a] attracts stress away from the default position: [ʃikáɾ] 'a hunt' cf. [dʒája] 'let's go'. However, results from a production experiment showed that stress consistently falls on the penultimate syllable. Of the five types of phonetic evidence examined, only F1 provides clear evidence for penultimate stress. So, the results from Gujarati support the claim that stress assignment is not influenced by vowel sonority.

This dissertation also presented an extensive typological survey of languages with

putative sonority-driven stress systems (see chapter 5). I have shown that many descriptions are impressionistic and lack phonetic or phonological evidence to support the described metrical structure. Even for descriptions with potential evidence for stress, I have argued that they are either weak or not relevant to metrical structure.

Finally, this dissertation has proposed a framework for understanding the typology of non-moraic segments. Crucially, this framework provides alternative views of sonority-driven stress and vowel neutralization.

• *Sonority-driven stress*

As discussed in detail in chapter 5, many languages are reported to have sonority-driven stress systems. The majority of the descriptions report that stress avoids landing on schwa. However, it is often not clear what the prosodic status schwa has, as its acoustic realization can be easily influenced by other factors (see chapter 3). So, there is a need for future phonetic analyses to elucidate the moraic status of schwa.

Finally, as shown in chapter 5, the factorial typology generates 86 distinct groups with various kinds of combination of moraic and non-moraic schwa. Although these groups are theoretically possible, it is not clear whether they are all empirically attested. Future investigation is required to find out whether other restrictions relevant to non-moraic schwa exist.

• *Vowel neutralization*

As proposed in Crosswhite (1999), vowel reduction with the outputs [i, u, ə] can be viewed as an instantiation of non-moraic segments. This suggests that the outputs are in fact [j, w,

ᵊ], and they should be acoustically distinct from their counterparts in the head position of a foot. A close phonetic analysis would reveal the extent of reduction, and the status of reduction as either resulting in a moraic or non-moraic vowel.

In conclusion, by no means has this dissertation provided evidence for every aspect of non-moraic schwa. While it has presented proposals for many of the core aspects of non-moraic schwa, a number of issues and languages remain to be explored or re-evaluated in light of the issues raised herein.

Appendix A: Piuma Paiwan native word stimuli

Word-form	IPA	Roman letters	Gloss
Cu.Cu (7 words)	ku.ku	kuku	toy
	tu.tu	tutu	breast
	tsu.qu	cuqu	bishop wood
	ku.tsu	kucu	head lice
	qu.lu	qulu	head
	tsu.su	cusu	to string something together
	su.pu	supu	total
Cu.CuC (7 words)	pu.qut	puqut	joint
	lu.kuts	lukuc	bird's-nest fern
	lu.cuk	lutjuk	rabbit
	tsu.qus	cuqus	stem
	su.suq	susuq	to sneak away
	lu.kuʎ	lukulj	coffin
	lu.tud	lutud	pain
Cə.Cu (11 words)	tə.ku	teku	low
	qə.pu	qepu	to summon
	və.tsu	vecu	cocoon
	və.ku	veku	wart
	sə.qu	sequ	odor
	tsə.pu	cepu	to weave
	ʎə.qu	ljequ	owl
	sə.pu	sepu	to infect
	sə.tu	setu	numb
	lə.ku	leku	ground oven
	ɟə.su	djesu	spring water
Cə.CuC (6 words)	ʎə.put	ljeput	a candle that gradually goes out
	lə.quts	lequc	greedy
	pə.cuq	petjuq	to break away
	qə.cuc	qetjutj	to fart
	sə.luts	seluc	trap
	tsə.buk	cebuk	sound of falling
Cə.CəC (11 words)	pə.təq	peteq	to break
	lə.pəts	lepec	a square linen to wear for funerals
	tə.tsək	tecek	needle
	tsə.kəs	cekes	bamboo
	ɟə.kəts	djekec	rice crust
	lə.kəts	lekec	the back of the knee
	qə.təp	qetep	juice
	sə.pət	sepet	to wring out

	sə.qəc	seqetj	to save
	tsə.gəd	ceged	invitation
	sə.kəz	sekez	to stop
Cu.CəC (8 words)	tsu.kəs	cukes	ancestral spirit column
	pu.dək	pudek	belly button
	tu.lək	tulek	to direct
	lu.səq	luseq	tears
	ʎu.qəs	ljuqes	bone marrow
	tsu.ləq	culeq	woodpecker
	pu.səd	pused	to be in heat
	ʎu.pəc	ljupetj	bottle stopper

Appendix B: Piuma Paiwan wug word stimuli

Word-form	IPA	Roman letters
Cu.Cu (3 words)	du.tu	dutu
	pu.tu	putu
	ku.tu	kutu
Cu.CuC (5 words)	tu.tut	tutut
	pu.tut	putut
	ku.tut	kutut
	tu.tup	tutup
	tu.tuk	tutuk
Cə.Cu (6 words)	tə.tu	tetu
	tə.pu	tepu
	də.ku	deku
	tə.tu	tetu
	pə.tu	petu
	gə.tu	getu
Cə.CuC (5 words)	tə.tut	tetut
	tə.tup	tetup
	tə.tuk	tetuk
	pə.tut	petut
	kə.tut	ketut
Cu.CəC (5 words)	pu.tət	putet
	ku.tət	kutet
	tu.tət	tutet
	tu.təp	tutep
	tu.tək	tutek
Cə.CəC (5 words)	tə.tət	tetet
	pə.tət	petet
	kə.tət	ketet
	tə.təp	tetep
	tə.tək	tetek
Cu.Cu.Cu (3 words)	tu.tu.tu	tututu
	tu.pu.tu	tuputu
	tu.ku.tu	tukutu
Cu.Cu.CuC (6 words)	tu.tu.tut	tututut
	tu.pu.tut	tuputut
	tu.ku.tut	tukutut
	tu.tu.tut	tututut
	pu.tu.tut	pututut
	ku.tu.tut	kututut
Cu.Cə.Cu (3 words)	tu.tə.tu	tutetu
	pu.tə.tu	putetu
	ku.tə.tu	kutetu

Cu.Cə.CuC (3 words)	tu.tə.tut	tutetut
	pu.tə.tut	putetut
	ku.tə.tut	kutetut
Cu.Cə.CəC (3 words)	tu.tə.tət	tutetet
	pu.tə.tət	putetet
	ku.tə.tət	kutetet

Appendix C: Gujarati experiment stimuli

Abbreviations: fem. = feminine, masc. = masculine, neut. = neuter

Word-form	IPA	Script	Gloss
Ca.Ca (10 words)	ka.ka	કાકા	paternal uncle
	pa.ka	પાકા	ripe, ready to eat
	ba.pa	બાપા	god
	kʰa.ta	ખાતા	while eating
	ta.ka	તાકા	stitches
	ka.pa	કાપા	cutting remarks
	ka.tʰa	કાથા	catechu
	pa.ta	પાતા	*nonce word*
	ba.ta	બાતા	*nonce word*
	dʰa.ka	ધાકા	*nonce word*
Ca.Co (5 words)	ka.po	કાપો	to cut (masc.)
	pa.ko	પાકો	ripe (masc.)
	ba.po	બાપો	father
	pa.po	પાપો	sins
	bʰa.to	ભાતો	designs
Co.Ca (5 words)	po.ta	પોતા	mine
	bo.kʰa	બોખા	a person without teeth
	kʰo.kʰa	ખોખા	boxes
	tʰo.tʰa	થોથા	stacks
	ko.ta	કોતા	*nonce word*
Ca.Ci (5 words)	ka.ki	કાકી	a paternal uncle's wife
	ta.ki	તાકી	to stare
	pa.ki	પાકી	ripe (fem.)
	ga.ti	ગાતી	sang (fem.)
	ka.pi	કાપી	to cut (fem.)
Ci.Ca (5 words)	pi.ta	પિતા	father
	ki.ka	કીકા	small child
	bi.ta	બીતા	being frightened
	pi.tʰa	પીથા	*nonce word*
	gi.pa	ગીપા	*nonce word*
Ca.Cu (5 words)	ba.pu	બાપુ	type of priest
	ka.pu	કાપુ	want me to cut?
	ga.tu	ગાતુ	sang (neut.)
	bʰa.tʰu	ભાથુ	food
	ba.kʰu	બાખુ	hole

Cu.Ca (5 words)	bʰu.ka	ભુકા	pieces
	pu.tʰa	પુથા	*nonce word*
	pu.ka	પૂકા	*nonce word*
	pu.ta	પૂતા	*nonce word*
	bʰu.pa	ભૂપા	*nonce word*
Co.Co (5 words)	kʰo.kʰo	ખોખો	tag games
	bo.kʰo	બોખો	a person without teeth (masc.)
	go.kʰo	ગોખો	mug up
	go.to	ગોતો	order someone to search
	dʰo.ko	ધોકો	use a stick to beat up the clothes
Ci.Ci (5 words)	ti.kʰi	તીખી	spicy (fem.)
	pi.kʰi	પીખી	disrupt (fem.)
	pi.ti	પીતી	drank (fem.)
	ti.tʰi	તિથી	date in Indian calendar
	bʰi.ti	ભીતિ	intuition
Cu.Cu (5 words)	gu.tʰu	ગૂથુ	to weave
	gʰu.pu	ધૂપૂ	*nonce word*
	dʰu.pu	ધૂપૂ	*nonce word*
	bu.tʰu	બુથૂ	*nonce word*
	ku.pu	ફૂપૂ	*nonce word*

Appendix D: The typology with 86 groups

Violations

	AllFtL	AllFtR	FtBinμ	FtBinσ	Trochee	Iamb	*μ/ə	Hdσ
('CV)CVCV		2	1	1				
('CV)CVCə		2	1	1			1	
('CV)CVCᵊ		2	1	1				1
('CV)CəCV		2	1	1			1	
('CV)CəCə		2	1	1			2	
('CV)CəCᵊ		2	1	1			1	1
('CV)CᵊCV		2	1	1				1
('CV)CᵊCə		2	1	1			1	1
('CV)CᵊCᵊ		2	1	1				2
('Cə)CVCV		2	1	1			1	
('Cə)CVCə		2	1	1			2	
('Cə)CVCᵊ		2	1	1			1	1
('Cə)CəCV		2	1	1			2	
('Cə)CəCə		2	1	1			3	
('Cə)CəCᵊ		2	1	1			2	1
('Cə)CᵊCV		2	1	1			1	1
('Cə)CᵊCə		2	1	1			2	1
('Cə)CᵊCᵊ		2	1	1			1	2
(Cᵊ)CVCV		2	1	1	1	1		1
(Cᵊ)CVCə		2	1	1	1	1	1	1
(Cᵊ)CVCᵊ		2	1	1	1	1		2
(Cᵊ)CəCV		2	1	1	1	1	1	1
(Cᵊ)CəCə		2	1	1	1	1	2	1
(Cᵊ)CəCᵊ		2	1	1	1	1	1	2
(Cᵊ)CᵊCV		2	1	1	1	1		2
(Cᵊ)CᵊCə		2	1	1	1	1	1	2
(Cᵊ)CᵊCᵊ		2	1	1	1	1		3
CV('CV)CV	1	1	1	1				
('CVCV)CV		1				1		
CVCV('CV)	2		1	1				
CV('CVCV)	1					1		
CV('CV)Cə	1	1	1	1			1	
('CVCV)Cə		1				1	1	
CVCV('Cə)	2		1	1			1	
CV('CVCə)	1					1	1	
CV('CV)Cᵊ	1	1	1	1				1

	ALLFTL	ALLFTR	FTBINµ	FTBINσ	TROCHEE	IAMB	*µ/ə	HDσ
('CVCV)Cᵊ		1				1		1
CVCV(Cᵊ)	2		1	1	1	1		1
CV('CVCᵊ)	1		1			1		1
CV('Cə)CV	1	1	1	1			1	
('CVCə)CV		1				1	1	
CVCə('CV)	2		1	1			1	
CV('CəCV)	1					1	1	
CV('Cə)Cə	1	1	1	1			2	
('CVCə)Cə		1				1	2	
CVCə('Cə)	2		1	1			2	
CV('CəCə)	1					1	2	
CV('Cə)Cᵊ	1	1	1	1			1	1
('CVCə)Cᵊ		1				1	1	1
CVCə(Cᵊ)	2		1	1	1	1	1	1
CV('CəCᵊ)	1		1			1	1	1
CV(Cᵊ)CV	1	1	1	1	1	1		1
('CVCᵊ)CV		1	1			1		1
CVCᵊ('CV)	2		1	1				1
CV(Cᵊ'CV)	1		1		1			1
CV(Cᵊ)Cə	1	1	1	1	1	1	1	1
('CVCᵊ)Cə		1	1			1	1	1
CVCᵊ('Cə)	2		1	1			1	1
CV(Cᵊ'Cə)	1		1		1		1	1
CV(Cᵊ)Cᵊ	1	1	1	1	1	1		2
('CVCᵊ)Cᵊ		1	1			1		2
CVCᵊ(Cᵊ)	2		1	1	1	1		2
CV(CᵊCᵊ)	1		1		1	1		2
Cə('CV)CV	1	1	1	1			1	
('CəCV)CV		1				1	1	
CəCV('CV)	2		1	1			1	
Cə('CVCV)	1					1	1	
Cə('CV)Cə	1	1	1	1			2	
('CəCV)Cə		1				1	2	
CəCV('Cə)	2		1	1			2	
Cə('CVCə)	1					1	2	
Cə('CV)Cᵊ	1	1	1	1			1	1
('CəCV)Cᵊ		1				1	1	1
CəCV(Cᵊ)	2		1	1	1	1	1	1
Cə('CVCᵊ)	1		1			1	1	1
Cə('Cə)CV	1	1	1	1			2	
('CəCə)CV		1				1	2	

	ALLFTL	ALLFTR	FTBINµ	FTBINσ	TROCHEE	IAMB	*µ/ə	HDσ
CəCə('CV)	2		1	1			2	
Cə('CəCV)	1					1	2	
Cə('Cə)Cə	1	1	1	1			3	
('CəCə)Cə		1				1	3	
CəCə('Cə)	2		1	1			3	
Cə('CəCə)	1					1	3	
Cə('Cə)Cᵊ	1	1	1	1			2	1
('CəCə)Cᵊ		1				1	2	1
CəCə(Cᵊ)	2		1	1	1	1	2	1
Cə('CəCᵊ)	1		1			1	2	1
Cə(Cᵊ)CV	1	1	1	1	1	1	1	1
('CəCᵊ)CV		1	1			1	1	1
CəCᵊ('CV)	2		1	1			1	1
Cə(Cᵊ'CV)	1		1		1		1	1
Cə(Cᵊ)Cə	1	1	1	1	1	1	2	1
('CəCᵊ)Cə		1	1			1	2	1
CəCᵊ('Cə)	2		1	1			2	1
Cə(Cᵊ'Cə)	1		1		1		2	1
Cə(Cᵊ)Cᵊ	1	1	1	1	1	1	1	2
('CəCᵊ)Cᵊ		1	1			1	1	2
CəCᵊ(Cᵊ)	2		1	1	1	1	1	2
Cə(CᵊCᵊ)	1		1		1	1	1	2
Cᵊ('CV)CV	1	1	1	1				1
(Cᵊ'CV)CV		1	1		1			1
CᵊCV('CV)	2		1	1				1
Cᵊ('CVCV)	1					1		1
Cᵊ('CV)Cə	1	1	1	1			1	1
(Cᵊ'CV)Cə		1	1		1		1	1
CᵊCV('Cə)	2		1	1			1	1
Cᵊ('CVCə)	1					1	1	1
Cᵊ('CV)Cᵊ	1	1	1	1				2
(Cᵊ'CV)Cᵊ		1	1		1			2
CᵊCV(Cᵊ)	2		1	1	1	1		2
Cᵊ('CVCᵊ)	1		1			1		2
Cᵊ('Cə)CV	1	1	1	1			1	1
(Cᵊ'Cə)CV		1	1		1		1	1
CᵊCə('CV)	2		1	1			1	1
Cᵊ('CəCV)	1					1	1	1
Cᵊ('Cə)Cə	1	1	1	1			2	1
(Cᵊ'Cə)Cə		1	1		1		2	1
CᵊCə('Cə)	2		1	1			2	1

	ALLFTL	ALLFTR	FTBINμ	FTBINσ	TROCHEE	IAMB	*μ/ə	HDσ
Cᵊ('CəCə)	1					1	2	1
Cᵊ('Cə)Cᵊ	1	1	1	1			1	2
(Cᵊ'Cə)Cᵊ		1	1		1		1	2
CᵊCə(Cᵊ)	2		1	1	1	1	1	2
Cᵊ('CəCᵊ)	1		1			1	1	2
Cᵊ(Cᵊ)CV	1	1	1	1	1	1		2
(CᵊCᵊ)CV		1	1		1	1		2
CᵊCᵊ('CV)	2		1	1				2
Cᵊ(Cᵊ'CV)	1		1		1			2
Cᵊ(Cᵊ)Cə	1	1	1	1	1	1	1	2
(CᵊCᵊ)Cə		1	1		1	1	1	2
CᵊCᵊ('Cə)	2		1	1			1	2
Cᵊ(Cᵊ'Cə)	1		1		1		1	2
Cᵊ(Cᵊ)Cᵊ	1	1	1	1	1	1		3
(CᵊCᵊ)Cᵊ		1	1		1	1		3
CᵊCᵊ(Cᵊ)	2		1	1	1	1		3
Cᵊ(CᵊCᵊ)	1		1		1	1		3
(CV'CV)CV		1			1			
CV(CV'CV)	1				1			
(CV'CV)Cə		1			1		1	
CV(CV'Cə)	1				1		1	
(CV'CV)Cᵊ		1			1			1
(CV'Cə)CV		1			1		1	
CV(Cə'CV)	1				1		1	
(CV'Cə)Cə		1			1		2	
CV(Cə'Cə)	1				1		2	
(CV'Cə)Cᵊ		1			1		1	1
(Cə'CV)CV		1			1		1	
Cə(CV'CV)	1				1		1	
(Cə'CV)Cə		1			1		2	
Cə(CV'Cə)	1				1		2	
(Cə'CV)Cᵊ		1			1		1	1
(Cə'Cə)CV		1			1		2	
Cə(Cə'CV)	1				1		2	
(Cə'Cə)Cə		1			1		3	
Cə(Cə'Cə)	1				1		3	
(Cə'Cə)Cᵊ		1			1		2	1
Cᵊ(CV'CV)	1				1			1
Cᵊ(CV'Cə)	1				1		1	1
Cᵊ(Cə'CV)	1				1		1	1
Cᵊ(Cə'Cə)	1				1		2	1

Grammars

Total number of rankings calculated (8!):40320

Here are the Groups of grammars in terms of their Input → Output mappings. Common rankings for each group is provided. A common ranking within a group is a ranking that all members of the group share. The common rankings only include individual constraint rankings. They do not include disjunctive common rankings (e.g. where c_1 *or* c_2 always outrank c_3).

Group #0

The following grammars have these IO pairs:

/CVCVCV/ → ('CVCV)CV

/CVCVCə/ → ('CVCV)Cᵊ

/CVCəCV/ → ('CVCə)CV

/CəCVCV/ → ('CəCV)CV

/CVCəCə/ → ('CVCə)Cᵊ

/CəCVCə/ → ('CəCV)Cᵊ

/CəCəCV/ → ('CəCə)CV

/CəCəCə/ → ('CəCə)Cᵊ

The number of rankings that produce these mappings is:1094

They all share the following rankings:

- AllFtL » AllFtR, *μ/ə, Hd-σ
- FtBinμ » *μ/ə, Hd-σ
- Trochee » Iamb
- *μ/ə » Hd-σ

Group #1

The following grammars have these IO pairs:

/CVCVCV/ → ('CVCV)CV

/CVCVCə/ → ('CVCV)Cə

/CVCəCV/ → ('CVCə)CV

/CəCVCV/ → ('CəCV)CV

/CVCəCə/ → ('CVCə)Cə

/CəCVCə/ → ('CəCV)Cə

/CəCəCV/ → ('CəCə)CV

/CəCəCə/ → ('CəCə)Cə

The number of rankings that produce these mappings is:4368

They all share the following rankings:

- AllFtL » AllFtR
- Trochee » Iamb
- Hd-σ » *μ/ə

Group #2

The following grammars have these IO pairs:

/CVCVCV/ → (CV'CV)CV

/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → (CV'Cə)CV
/CəCVCV/ → (Cə'CV)CV
/CVCəCə/ → (CV'Cə)Cᵊ
/CəCVCə/ → (Cə'CV)Cᵊ
/CəCəCV/ → (Cə'Cə)CV
/CəCəCə/ → (Cə'Cə)Cᵊ
The number of rankings that produce these mappings is:1094
They all share the following rankings:
● AllFtL » AllFtR, *μ/ə, Hd-σ
● FtBinμ » *μ/ə, Hd-σ
● Iamb » Trochee
● *μ/ə » Hd-σ

Group #3
The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cə
/CVCəCV/ → (CV'Cə)CV
/CəCVCV/ → (Cə'CV)CV
/CVCəCə/ → (CV'Cə)Cə
/CəCVCə/ → (Cə'CV)Cə
/CəCəCV/ → (Cə'Cə)CV
/CəCəCə/ → (Cə'Cə)Cə
The number of rankings that produce these mappings is:4368
They all share the following rankings:
● AllFtL » AllFtR
● Iamb » Trochee
● Hd-σ » *μ/ə

Group #4
The following grammars have these IO pairs:
/CVCVCV/ → ('CVCV)CV
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → ('CVCᵊ)CV
/CəCVCV/ → ('CəCV)CV
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → ('CəCV)Cᵊ
/CəCəCV/ → ('CəCᵊ)CV
/CəCəCə/ → ('CəCᵊ)Cᵊ
The number of rankings that produce these mappings is:560
They all share the following rankings:
● AllFtL » AllFtR, *μ/ə, FtBinμ, Hd-σ
● Trochee » Iamb, *μ/ə, FtBinμ, Hd-σ

● *μ/ə » FtBinμ, Hd-σ

Group #5
The following grammars have these IO pairs:

/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → (CV'Cə)CV
/CəCVCV/ → (Cᵊ'CV)CV
/CVCəCə/ → (CV'Cə)Cᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → (Cᵊ'Cə)CV
/CəCəCə/ → (Cᵊ'Cə)Cᵊ

The number of rankings that produce these mappings is:400
They all share the following rankings:
● AllFtL » AllFtR, *μ/ə, FtBinμ, Hd-σ
● Iamb » Trochee, *μ/ə, FtBinμ, Hd-σ
● *μ/ə » FtBinμ, Hd-σ

Group #6
The following grammars have these IO pairs:

/CVCVCV/ → ('CVCV)CV
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → ('CVCᵊ)CV
/CəCVCV/ → (Cᵊ'CV)CV
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → (CᵊCᵊ)CV
/CəCəCə/ → (CᵊCᵊ)Cᵊ

The number of rankings that produce these mappings is:1022
They all share the following rankings:
● AllFtL » AllFtR, FtBinμ, Trochee, Iamb
● *μ/ə » FtBinμ, Trochee, Iamb, Hd-σ
● Trochee » Iamb

Group #7
The following grammars have these IO pairs:

/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → ('CVCᵊ)CV
/CəCVCV/ → (Cᵊ'CV)CV
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → (CᵊCᵊ)CV
/CəCəCə/ → (CᵊCᵊ)Cᵊ

The number of rankings that produce these mappings is:762
They all share the following rankings:
- AllFtL » AllFtR, FtBinμ, Iamb, Trochee
- *μ/ə » FtBinμ, Iamb, Trochee, Hd-σ
- Iamb » Trochee

Group #8
The following grammars have these IO pairs:
/CVCVCV/ → ('CVCV)CV
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → ('CV)CᵊCV
/CəCVCV/ → ('CəCV)CV
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → ('CəCV)Cᵊ
/CəCəCV/ → ('Cə)CᵊCV
/CəCəCə/ → ('Cə)CᵊCᵊ
The number of rankings that produce these mappings is:20
They all share the following rankings:
- AllFtL » *μ/ə, FtBinμ, Iamb, AllFtR, FtBinσ, Hd-σ
- Trochee » *μ/ə, FtBinμ, Iamb, AllFtR, FtBinσ, Hd-σ
- *μ/ə » FtBinμ, Iamb, AllFtR, FtBinσ, Hd-σ
- FtBinμ » Iamb, AllFtR, FtBinσ
- Iamb » AllFtR, FtBinσ

Group #9
The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → ('CV)CᵊCV
/CəCVCV/ → (Cᵊ'CV)CV
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → (Cᵊ'Cə)CV
/CəCəCə/ → (Cᵊ'Cə)Cᵊ
The number of rankings that produce these mappings is:160
They all share the following rankings:
- AllFtL » *μ/ə, AllFtR, FtBinμ, FtBinσ, Trochee, Hd-σ
- Iamb » *μ/ə, AllFtR, FtBinμ, FtBinσ, Trochee, Hd-σ
- *μ/ə » AllFtR, FtBinμ, FtBinσ, Trochee, Hd-σ

Group #10
The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → ('CV)CᵊCV

/CəCVCV/ → (Cᵊ'CV)CV
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → ('Cə)CᵊCV
/CəCəCə/ → ('Cə)CᵊCᵊ
The number of rankings that produce these mappings is:20
They all share the following rankings:
● AllFtL » *µ/ə, FtBinµ, Trochee, AllFtR, FtBinσ, Hd-σ
● Iamb » *µ/ə, FtBinµ, Trochee, AllFtR, FtBinσ, Hd-σ
● *µ/ə » FtBinµ, Trochee, AllFtR, FtBinσ, Hd-σ
● FtBinµ » Trochee, AllFtR, FtBinσ
● Trochee » AllFtR, FtBinσ

Group #11
The following grammars have these IO pairs:
/CVCVCV/ → ('CVCV)CV
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → ('CV)CᵊCV
/CəCVCV/ → (Cᵊ'CV)CV
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → (CᵊCᵊ)CV
/CəCəCə/ → (CᵊCᵊ)Cᵊ
The number of rankings that produce these mappings is:52
They all share the following rankings:
● AllFtL » FtBinµ, Trochee, Iamb, AllFtR, FtBinσ
● *µ/ə » FtBinµ, Trochee, Iamb, AllFtR, FtBinσ, Hd-σ
● FtBinµ » Iamb, AllFtR, FtBinσ
● Trochee » Iamb, AllFtR, FtBinσ
● Iamb » AllFtR, FtBinσ

Group #12
The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → ('CV)CᵊCV
/CəCVCV/ → (Cᵊ'CV)CV
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → (CᵊCᵊ)CV
/CəCəCə/ → (CᵊCᵊ)Cᵊ
The number of rankings that produce these mappings is:312
They all share the following rankings:
● AllFtL » FtBinµ, Iamb, AllFtR, FtBinσ, Trochee
● *µ/ə » FtBinµ, Iamb, AllFtR, FtBinσ, Trochee, Hd-σ

● Iamb » AllFtR, FtBinσ, Trochee

Group #13
The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → CV('CVCə)
/CVCəCV/ → CV('CəCV)
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → CV('CəCə)
/CəCVCə/ → Cᵊ('CVCə)
/CəCəCV/ → Cᵊ('CəCV)
/CəCəCə/ → Cᵊ('CəCə)
The number of rankings that produce these mappings is:1094
They all share the following rankings:
● AllFtR » AllFtL, *μ/ə, Hd-σ
● FtBinμ » *μ/ə, Hd-σ
● Trochee » Iamb
● *μ/ə » Hd-σ

Group #14
The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → CV('CVCə)
/CVCəCV/ → CV('CəCV)
/CəCVCV/ → Cə('CVCV)
/CVCəCə/ → CV('CəCə)
/CəCVCə/ → Cə('CVCə)
/CəCəCV/ → Cə('CəCV)
/CəCəCə/ → Cə('CəCə)
The number of rankings that produce these mappings is:4368
They all share the following rankings:
● AllFtR » AllFtL
● Trochee » Iamb
● Hd-σ » *μ/ə

Group #15
The following grammars have these IO pairs:
/CVCVCV/ → CV(CV'CV)
/CVCVCə/ → CV(CV'Cə)
/CVCəCV/ → CV(Cə'CV)
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → CV(Cə'Cə)
/CəCVCə/ → Cᵊ(CV'Cə)
/CəCəCV/ → Cᵊ(Cə'CV)

/CəCəCə/ → Cᵊ(Cə'Cə)

The number of rankings that produce these mappings is:1094

They all share the following rankings:

- AllFtR » AllFtL, *μ/ə, Hd-σ
- FtBinμ » *μ/ə, Hd-σ
- Iamb » Trochee
- *μ/ə » Hd-σ

Group #16

The following grammars have these IO pairs:

/CVCVCV/ → CV(CV'CV)

/CVCVCə/ → CV(CV'Cə)

/CVCəCV/ → CV(Cə'CV)

/CəCVCV/ → Cə(CV'CV)

/CVCəCə/ → CV(Cə'Cə)

/CəCVCə/ → Cə(CV'Cə)

/CəCəCV/ → Cə(Cə'CV)

/CəCəCə/ → Cə(Cə'Cə)

The number of rankings that produce these mappings is:4368

They all share the following rankings:

- AllFtR » AllFtL
- Iamb » Trochee
- Hd-σ » *μ/ə

Group #17

The following grammars have these IO pairs:

/CVCVCV/ → CV('CVCV)

/CVCVCə/ → CV('CVCᵊ)

/CVCəCV/ → CV('CəCV)

/CəCVCV/ → Cᵊ('CVCV)

/CVCəCə/ → CV('CəCᵊ)

/CəCVCə/ → Cᵊ('CVCᵊ)

/CəCəCV/ → Cᵊ('CəCV)

/CəCəCə/ → Cᵊ('CəCᵊ)

The number of rankings that produce these mappings is:400

They all share the following rankings:

- AllFtR » AllFtL, *μ/ə, FtBinμ, Hd-σ
- Trochee » Iamb, *μ/ə, FtBinμ, Hd-σ
- *μ/ə » FtBinμ, Hd-σ

Group #18

The following grammars have these IO pairs:

/CVCVCV/ → CV(CV'CV)

/CVCVCə/ → CV(CV'Cə)

/CVCəCV/ → CV(CᵊˈCV)
/CəCVCV/ → Cᵊ(CVˈCV)
/CVCəCə/ → CV(CᵊˈCə)
/CəCVCə/ → Cᵊ(CVˈCə)
/CəCəCV/ → Cᵊ(CᵊˈCV)
/CəCəCə/ → Cᵊ(CᵊˈCə)

The number of rankings that produce these mappings is:560
They all share the following rankings:
- AllFtR » AllFtL, *μ/ə, FtBinμ, Hd-σ
- Iamb » Trochee, *μ/ə, FtBinμ, Hd-σ
- *μ/ə » FtBinμ, Hd-σ

Group #19

The following grammars have these IO pairs:
/CVCVCV/ → CV(ˈCVCV)
/CVCVCə/ → CV(ˈCVCᵊ)
/CVCəCV/ → CV(CᵊˈCV)
/CəCVCV/ → Cᵊ(ˈCVCV)
/CVCəCə/ → CV(CᵊCᵊ)
/CəCVCə/ → Cᵊ(ˈCVCᵊ)
/CəCəCV/ → Cᵊ(CᵊˈCV)
/CəCəCə/ → Cᵊ(CᵊCᵊ)

The number of rankings that produce these mappings is:762
They all share the following rankings:
- AllFtR » AllFtL, FtBinμ, Trochee, Iamb
- *μ/ə » FtBinμ, Trochee, Iamb, Hd-σ
- Trochee » Iamb

Group #20

The following grammars have these IO pairs:
/CVCVCV/ → CV(CVˈCV)
/CVCVCə/ → CV(ˈCVCᵊ)
/CVCəCV/ → CV(CᵊˈCV)
/CəCVCV/ → Cᵊ(CVˈCV)
/CVCəCə/ → CV(CᵊCᵊ)
/CəCVCə/ → Cᵊ(ˈCVCᵊ)
/CəCəCV/ → Cᵊ(CᵊˈCV)
/CəCəCə/ → Cᵊ(CᵊCᵊ)

The number of rankings that produce these mappings is:1022
They all share the following rankings:
- AllFtR » AllFtL, FtBinμ, Iamb, Trochee
- *μ/ə » FtBinμ, Iamb, Trochee, Hd-σ
- Iamb » Trochee

Group #21

The following grammars have these IO pairs:

/CVCVCV/ → CV('CVCV)
/CVCVCə/ → CV('CVCᵊ)
/CVCəCV/ → CVCᵊ('CV)
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → CV('CəCᵊ)
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → Cᵊ('CəCᵊ)

The number of rankings that produce these mappings is:160
They all share the following rankings:
● AllFtR » *µ/ə, AllFtL, FtBinµ, FtBinσ, Iamb, Hd-σ
● Trochee » *µ/ə, AllFtL, FtBinµ, FtBinσ, Iamb, Hd-σ
● *µ/ə » AllFtL, FtBinµ, FtBinσ, Iamb, Hd-σ

Group #22

The following grammars have these IO pairs:

/CVCVCV/ → CV('CVCV)
/CVCVCə/ → CV('CVCᵊ)
/CVCəCV/ → CVCᵊ('CV)
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → CVCᵊ('Cə)
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → CᵊCᵊ('Cə)

The number of rankings that produce these mappings is:20
They all share the following rankings:
● AllFtR » *µ/ə, FtBinµ, Iamb, AllFtL, FtBinσ, Hd-σ
● Trochee » *µ/ə, FtBinµ, Iamb, AllFtL, FtBinσ, Hd-σ
● *µ/ə » FtBinµ, Iamb, AllFtL, FtBinσ, Hd-σ
● FtBinµ » Iamb, AllFtL, FtBinσ
● Iamb » AllFtL, FtBinσ

Group #23

The following grammars have these IO pairs:

/CVCVCV/ → CV(CV'CV)
/CVCVCə/ → CV(CV'Cə)
/CVCəCV/ → CVCᵊ('CV)
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → CVCᵊ('Cə)
/CəCVCə/ → Cᵊ(CV'Cə)
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → CᵊCᵊ('Cə)

The number of rankings that produce these mappings is:20
They all share the following rankings:
- AllFtR » *μ/ə, FtBinμ, Trochee, AllFtL, FtBinσ, Hd-σ
- Iamb » *μ/ə, FtBinμ, Trochee, AllFtL, FtBinσ, Hd-σ
- *μ/ə » FtBinμ, Trochee, AllFtL, FtBinσ, Hd-σ
- FtBinμ » Trochee, AllFtL, FtBinσ
- Trochee » AllFtL, FtBinσ

Group #24
The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → CV('CVCᵊ)
/CVCəCV/ → CVCᵊ('CV)
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → CV(CᵊCᵊ)
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → Cᵊ(CᵊCᵊ)
The number of rankings that produce these mappings is:312
They all share the following rankings:
- AllFtR » FtBinμ, Trochee, AllFtL, FtBinσ, Iamb
- *μ/ə » FtBinμ, Trochee, AllFtL, FtBinσ, Iamb, Hd-σ
- Trochee » AllFtL, FtBinσ, Iamb

Group #25
The following grammars have these IO pairs:
/CVCVCV/ → CV(CV'CV)
/CVCVCə/ → CV('CVCᵊ)
/CVCəCV/ → CVCᵊ('CV)
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → CV(CᵊCᵊ)
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → Cᵊ(CᵊCᵊ)
The number of rankings that produce these mappings is:52
They all share the following rankings:
- AllFtR » FtBinμ, Iamb, Trochee, AllFtL, FtBinσ
- *μ/ə » FtBinμ, Iamb, Trochee, AllFtL, FtBinσ, Hd-σ
- FtBinμ » Trochee, AllFtL, FtBinσ
- Iamb » Trochee, AllFtL, FtBinσ
- Trochee » AllFtL, FtBinσ

Group #26
The following grammars have these IO pairs:
/CVCVCV/ → ('CVCV)CV

/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → ('CVCə)CV
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CVCə)Cᵊ
/CəCVCə/ → ('CəCV)Cᵊ
/CəCəCV/ → Cᵊ('CəCV)
/CəCəCə/ → ('CəCə)Cᵊ
The number of rankings that produce these mappings is:486
They all share the following rankings:
● FtBinμ » *μ/ə, AllFtL, AllFtR, Hd-σ
● Trochee » Iamb
● *μ/ə » AllFtL, AllFtR, Hd-σ
● AllFtL » AllFtR

Group #27
The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → CV('CəCV)
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CVCə)Cᵊ
/CəCVCə/ → Cᵊ('CVCə)
/CəCəCV/ → Cᵊ('CəCV)
/CəCəCə/ → Cᵊ('CəCə)
The number of rankings that produce these mappings is:486
They all share the following rankings:
● FtBinμ » *μ/ə, AllFtR, AllFtL, Hd-σ
● Trochee » Iamb
● *μ/ə » AllFtR, AllFtL, Hd-σ
● AllFtR » AllFtL

Group #28
The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → (CV'Cə)CV
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → (CV'Cə)Cᵊ
/CəCVCə/ → (Cə'CV)Cᵊ
/CəCəCV/ → Cᵊ(Cə'CV)
/CəCəCə/ → (Cə'Cə)Cᵊ
The number of rankings that produce these mappings is:486
They all share the following rankings:
● FtBinμ » *μ/ə, AllFtL, AllFtR, Hd-σ

- Iamb » Trochee
- *μ/ə » AllFtL, AllFtR, Hd-σ
- AllFtL » AllFtR

Group #29
The following grammars have these IO pairs:
/CVCVCV/ → CV(CV'CV)
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → CV(Cə'CV)
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → (CV'Cə)Cᵊ
/CəCVCə/ → Cᵊ(CV'Cə)
/CəCəCV/ → Cᵊ(Cə'CV)
/CəCəCə/ → Cᵊ(Cə'Cə)
The number of rankings that produce these mappings is:486
They all share the following rankings:
- FtBinμ » *μ/ə, AllFtR, AllFtL, Hd-σ
- Iamb » Trochee
- *μ/ə » AllFtR, AllFtL, Hd-σ
- AllFtR » AllFtL

Group #30
The following grammars have these IO pairs:
/CVCVCV/ → ('CVCV)CV
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → ('CVCᵊ)CV
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → ('CəCᵊ)CV
/CəCəCə/ → ('CəCᵊ)Cᵊ
The number of rankings that produce these mappings is:96
They all share the following rankings:
- FtBinσ » Iamb, *μ/ə, AllFtL, AllFtR, FtBinμ, Hd-σ
- Trochee » Iamb, *μ/ə, AllFtL, AllFtR, FtBinμ, Hd-σ
- *μ/ə » AllFtL, AllFtR, FtBinμ, Hd-σ
- AllFtL » AllFtR, FtBinμ

Group #31
The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → CV('CVCᵊ)
/CVCəCV/ → ('CVCᵊ)CV
/CəCVCV/ → Cᵊ('CVCV)

/CVCəCə/ → ('CVCˀ)Cˀ
/CəCVCə/ → Cˀ('CVCˀ)
/CəCəCV/ → Cˀ('CəCV)
/CəCəCə/ → Cˀ('CəCˀ)
The number of rankings that produce these mappings is:96
They all share the following rankings:
● FtBinσ » Iamb, *μ/ə, AllFtR, AllFtL, FtBinμ, Hd-σ
● Trochee » Iamb, *μ/ə, AllFtR, AllFtL, FtBinμ, Hd-σ
● *μ/ə » AllFtR, AllFtL, FtBinμ, Hd-σ
● AllFtR » AllFtL, FtBinμ

Group #32
The following grammars have these IO pairs:
/CVCVCV/ → ('CVCV)CV
/CVCVCə/ → ('CVCV)Cˀ
/CVCəCV/ → ('CVCˀ)CV
/CəCVCV/ → Cˀ('CVCV)
/CVCəCə/ → ('CVCˀ)Cˀ
/CəCVCə/ → Cˀ('CVCˀ)
/CəCəCV/ → Cˀ('CəCV)
/CəCəCə/ → ('CəCˀ)Cˀ
The number of rankings that produce these mappings is:48
They all share the following rankings:
● FtBinσ » Iamb, *μ/ə, FtBinμ, AllFtL, AllFtR, Hd-σ
● Trochee » Iamb, *μ/ə, FtBinμ, AllFtL, AllFtR, Hd-σ
● *μ/ə » FtBinμ, AllFtL, AllFtR, Hd-σ
● FtBinμ » AllFtL, AllFtR
● AllFtL » AllFtR

Group #33
The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → ('CVCV)Cˀ
/CVCəCV/ → ('CVCˀ)CV
/CəCVCV/ → Cˀ('CVCV)
/CVCəCə/ → ('CVCˀ)Cˀ
/CəCVCə/ → Cˀ('CVCˀ)
/CəCəCV/ → Cˀ('CəCV)
/CəCəCə/ → Cˀ('CəCˀ)
The number of rankings that produce these mappings is:48
They all share the following rankings:
● FtBinσ » Iamb, *μ/ə, FtBinμ, AllFtR, AllFtL, Hd-σ
● Trochee » Iamb, *μ/ə, FtBinμ, AllFtR, AllFtL, Hd-σ
● *μ/ə » FtBinμ, AllFtR, AllFtL, Hd-σ
● FtBinμ » AllFtR, AllFtL

● AllFtR » AllFtL

Group #34
The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → CV(Cᵊ'CV)
/CəCVCV/ → (Cᵊ'CV)CV
/CVCəCə/ → (CV'Cə)Cᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → Cᵊ(Cᵊ'CV)
/CəCəCə/ → (Cᵊ'Cə)Cᵊ
The number of rankings that produce these mappings is:96
They all share the following rankings:
● FtBinσ » Trochee, *μ/ə, AllFtL, AllFtR, FtBinμ, Hd-σ
● Iamb » Trochee, *μ/ə, AllFtL, AllFtR, FtBinμ, Hd-σ
● *μ/ə » AllFtL, AllFtR, FtBinμ, Hd-σ
● AllFtL » AllFtR, FtBinμ

Group #35
The following grammars have these IO pairs:
/CVCVCV/ → CV(CV'CV)
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → CV(Cᵊ'CV)
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → CV(Cᵊ'Cə)
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → Cᵊ(Cᵊ'CV)
/CəCəCə/ → Cᵊ(Cᵊ'Cə)
The number of rankings that produce these mappings is:96
They all share the following rankings:
● FtBinσ » Trochee, *μ/ə, AllFtR, AllFtL, FtBinμ, Hd-σ
● Iamb » Trochee, *μ/ə, AllFtR, AllFtL, FtBinμ, Hd-σ
● *μ/ə » AllFtR, AllFtL, FtBinμ, Hd-σ
● AllFtR » AllFtL, FtBinμ

Group #36
The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → CV(Cᵊ'CV)
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → (CV'Cə)Cᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ

/CəCəCV/ → Cᵊ(Cᵊ'CV)

/CəCəCə/ → (Cᵊ'Cə)Cᵊ

The number of rankings that produce these mappings is:48

They all share the following rankings:

- FtBinσ » Trochee, *μ/ə, FtBinμ, AllFtL, AllFtR, Hd-σ
- Iamb » Trochee, *μ/ə, FtBinμ, AllFtL, AllFtR, Hd-σ
- *μ/ə » FtBinμ, AllFtL, AllFtR, Hd-σ
- FtBinμ » AllFtL, AllFtR
- AllFtL » AllFtR

Group #37

The following grammars have these IO pairs:

/CVCVCV/ → CV(CV'CV)

/CVCVCə/ → (CV'CV)Cᵊ

/CVCəCV/ → CV(Cᵊ'CV)

/CəCVCV/ → Cᵊ(CV'CV)

/CVCəCə/ → (CV'Cə)Cᵊ

/CəCVCə/ → (Cᵊ'CV)Cᵊ

/CəCəCV/ → Cᵊ(Cᵊ'CV)

/CəCəCə/ → Cᵊ(Cᵊ'Cə)

The number of rankings that produce these mappings is:48

They all share the following rankings:

- FtBinσ » Trochee, *μ/ə, FtBinμ, AllFtR, AllFtL, Hd-σ
- Iamb » Trochee, *μ/ə, FtBinμ, AllFtR, AllFtL, Hd-σ
- *μ/ə » FtBinμ, AllFtR, AllFtL, Hd-σ
- FtBinμ » AllFtR, AllFtL
- AllFtR » AllFtL

Group #38

The following grammars have these IO pairs:

/CVCVCV/ → ('CVCV)CV

/CVCVCə/ → ('CVCV)Cᵊ

/CVCəCV/ → ('CVCᵊ)CV

/CəCVCV/ → Cᵊ('CVCV)

/CVCəCə/ → ('CVCᵊ)Cᵊ

/CəCVCə/ → (Cᵊ'CV)Cᵊ

/CəCəCV/ → (CᵊCᵊ)CV

/CəCəCə/ → (CᵊCᵊ)Cᵊ

The number of rankings that produce these mappings is:130

They all share the following rankings:

- *μ/ə » FtBinμ, AllFtL, AllFtR, Trochee, Iamb, Hd-σ
- FtBinμ » AllFtL, AllFtR, Trochee, Iamb
- AllFtL » AllFtR, Trochee, Iamb
- Trochee » Iamb

Group #39
The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → ('CVCᵊ)CV
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → (CᵊCᵊ)CV
/CəCəCə/ → (CᵊCᵊ)Cᵊ
The number of rankings that produce these mappings is:102
They all share the following rankings:
● *μ/ə » FtBinμ, AllFtL, AllFtR, Iamb, Trochee, Hd-σ
● FtBinμ » AllFtL, AllFtR, Iamb, Trochee
● AllFtL » AllFtR, Iamb, Trochee
● Iamb » Trochee

Group #40
The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → CV(Cᵊ'CV)
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → CV(CᵊCᵊ)
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → Cᵊ(Cᵊ'CV)
/CəCəCə/ → Cᵊ(CᵊCᵊ)
The number of rankings that produce these mappings is:102
They all share the following rankings:
● *μ/ə » FtBinμ, AllFtR, AllFtL, Trochee, Iamb, Hd-σ
● FtBinμ » AllFtR, AllFtL, Trochee, Iamb
● AllFtR » AllFtL, Trochee, Iamb
● Trochee » Iamb

Group #41
The following grammars have these IO pairs:
/CVCVCV/ → CV(CV'CV)
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → CV(Cᵊ'CV)
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → CV(CᵊCᵊ)
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → Cᵊ(Cᵊ'CV)
/CəCəCə/ → Cᵊ(CᵊCᵊ)

The number of rankings that produce these mappings is:130
They all share the following rankings:
- *μ/ə » FtBinμ, AllFtR, AllFtL, Iamb, Trochee, Hd-σ
- FtBinμ » AllFtR, AllFtL, Iamb, Trochee
- AllFtR » AllFtL, Iamb, Trochee
- Iamb » Trochee

Group #42
The following grammars have these IO pairs:
/CVCVCV/ → ('CVCV)CV
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → ('CVCᵊ)CV
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → (CᵊCᵊ)CV
/CəCəCə/ → (CᵊCᵊ)Cᵊ
The number of rankings that produce these mappings is:144
They all share the following rankings:
- FtBinσ » Trochee, AllFtL, AllFtR, Iamb
- *μ/ə » FtBinμ, Trochee, AllFtL, AllFtR, Iamb, Hd-σ
- Trochee » AllFtL, AllFtR, Iamb
- AllFtL » AllFtR, Iamb

Group #43
The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → ('CVCᵊ)CV
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → Cᵊ(Cᵊ'CV)
/CəCəCə/ → Cᵊ(CᵊCᵊ)
The number of rankings that produce these mappings is:112
They all share the following rankings:
- FtBinσ » Trochee, AllFtR, AllFtL, Iamb
- *μ/ə » FtBinμ, Trochee, AllFtR, AllFtL, Iamb, Hd-σ
- FtBinμ » AllFtR, AllFtL
- Trochee » AllFtR, AllFtL, Iamb
- AllFtR » AllFtL

Group #44
The following grammars have these IO pairs:
/CVCVCV/ → ('CVCV)CV

/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → ('CVCᵊ)CV
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → Cᵊ(Cᵊ'CV)
/CəCəCə/ → (CᵊCᵊ)Cᵊ
The number of rankings that produce these mappings is:72
They all share the following rankings:
● FtBinσ » Trochee, Iamb, AllFtL, AllFtR
● *μ/ə » FtBinμ, Trochee, Iamb, AllFtL, AllFtR, Hd-σ
● Trochee » Iamb, AllFtL, AllFtR
● Iamb » AllFtL, AllFtR
● AllFtL » AllFtR

Group #45
The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → CV(Cᵊ'CV)
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → Cᵊ(Cᵊ'CV)
/CəCəCə/ → (CᵊCᵊ)Cᵊ
The number of rankings that produce these mappings is:112
They all share the following rankings:
● FtBinσ » Iamb, AllFtL, AllFtR, Trochee
● *μ/ə » FtBinμ, Iamb, AllFtL, AllFtR, Trochee, Hd-σ
● FtBinμ » AllFtL, AllFtR
● Iamb » AllFtL, AllFtR, Trochee
● AllFtL » AllFtR

Group #46
The following grammars have these IO pairs:
/CVCVCV/ → CV(CV'CV)
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → CV(Cᵊ'CV)
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → CV(CᵊCᵊ)
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → Cᵊ(Cᵊ'CV)
/CəCəCə/ → Cᵊ(CᵊCᵊ)
The number of rankings that produce these mappings is:144

They all share the following rankings:
- FtBinσ » Iamb, AllFtR, AllFtL, Trochee
- *μ/ə » FtBinμ, Iamb, AllFtR, AllFtL, Trochee, Hd-σ
- Iamb » AllFtR, AllFtL, Trochee
- AllFtR » AllFtL, Trochee

Group #47
The following grammars have these IO pairs:
/CVCVCV/ → CV(CV'CV)
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → CV(Cᵊ'CV)
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → Cᵊ(Cᵊ'CV)
/CəCəCə/ → Cᵊ(CᵊCᵊ)
The number of rankings that produce these mappings is:72
They all share the following rankings:
- FtBinσ » Iamb, Trochee, AllFtR, AllFtL
- *μ/ə » FtBinμ, Iamb, Trochee, AllFtR, AllFtL, Hd-σ
- Iamb » Trochee, AllFtR, AllFtL
- Trochee » AllFtR, AllFtL
- AllFtR » AllFtL

Group #48
The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → CV('CVCᵊ)
/CVCəCV/ → ('CVCᵊ)CV
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → Cᵊ(Cᵊ'CV)
/CəCəCə/ → Cᵊ(CᵊCᵊ)
The number of rankings that produce these mappings is:104
They all share the following rankings:
- FtBinσ » Trochee, AllFtR, AllFtL, FtBinμ, Iamb
- *μ/ə » Trochee, AllFtR, AllFtL, FtBinμ, Iamb, Hd-σ
- Trochee » AllFtR, AllFtL, FtBinμ, Iamb
- AllFtR » AllFtL, FtBinμ

Group #49
The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ

/CVCəCV/ → CV(Cᵊ'CV)
/CəCVCV/ → (Cᵊ'CV)CV
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → Cᵊ(Cᵊ'CV)
/CəCəCə/ → (CᵊCᵊ)Cᵊ
The number of rankings that produce these mappings is:104
They all share the following rankings:
● FtBinσ » Iamb, AllFtL, AllFtR, FtBinμ, Trochee
● *μ/ə » Iamb, AllFtL, AllFtR, FtBinμ, Trochee, Hd-σ
● Iamb » AllFtL, AllFtR, FtBinμ, Trochee
● AllFtL » AllFtR, FtBinμ

Group #50
The following grammars have these IO pairs:
/CVCVCV/ → ('CVCV)CV
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → ('CVCᵊ)CV
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → ('CəCᵊ)Cᵊ
The number of rankings that produce these mappings is:210
They all share the following rankings:
● Trochee » *μ/ə, AllFtL, AllFtR, FtBinμ, FtBinσ, Iamb, Hd-σ
● *μ/ə » AllFtL, AllFtR, FtBinμ, FtBinσ, Iamb, Hd-σ
● AllFtL » AllFtR

Group #51
The following grammars have these IO pairs:
/CVCVCV/ → ('CVCV)CV
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → ('CV)CᵊCV
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → Cᵊ('CV)Cᵊ
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → ('Cə)CᵊCᵊ
The number of rankings that produce these mappings is:42
They all share the following rankings:
● Trochee » *μ/ə, AllFtL, FtBinμ, Iamb, AllFtR, FtBinσ, Hd-σ
● *μ/ə » AllFtL, FtBinμ, Iamb, AllFtR, FtBinσ, Hd-σ
● AllFtL » AllFtR
● FtBinμ » Iamb, AllFtR, FtBinσ

● Iamb » AllFtR, FtBinσ

The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → CV('CVCᵊ)
/CVCəCV/ → CVCᵊ('CV)
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → Cᵊ('CəCᵊ)
The number of rankings that produce these mappings is:96
They all share the following rankings:
● Trochee » *μ/ə, AllFtR, AllFtL, FtBinμ, FtBinσ, Iamb, Hd-σ
● *μ/ə » AllFtR, AllFtL, FtBinμ, FtBinσ, Iamb, Hd-σ
● AllFtR » AllFtL, FtBinμ, FtBinσ, Iamb

The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → CV('CVCᵊ)
/CVCəCV/ → CVCᵊ('CV)
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → CᵊCᵊ('Cə)
The number of rankings that produce these mappings is:12
They all share the following rankings:
● Trochee » *μ/ə, AllFtR, FtBinμ, Iamb, AllFtL, FtBinσ, Hd-σ
● *μ/ə » AllFtR, FtBinμ, Iamb, AllFtL, FtBinσ, Hd-σ
● AllFtR » FtBinμ, Iamb, AllFtL, FtBinσ
● FtBinμ » Iamb, AllFtL, FtBinσ
● Iamb » AllFtL, FtBinσ

The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → CVCᵊ('CV)
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → Cᵊ('CVCᵊ)

/CəCəCV/ → CᵊCᵊ('CV)

/CəCəCə/ → Cᵊ('CəCᵊ)

The number of rankings that produce these mappings is:24

They all share the following rankings:

- Trochee » *μ/ə, FtBinμ, AllFtR, AllFtL, FtBinσ, Iamb, Hd-σ
- *μ/ə » FtBinμ, AllFtR, AllFtL, FtBinσ, Iamb, Hd-σ
- FtBinμ » AllFtR, AllFtL, FtBinσ, Iamb
- AllFtR » AllFtL, FtBinσ, Iamb

Group #55

The following grammars have these IO pairs:

/CVCVCV/ → CV('CVCV)

/CVCVCə/ → ('CVCV)Cᵊ

/CVCəCV/ → CVCᵊ('CV)

/CəCVCV/ → Cᵊ('CVCV)

/CVCəCə/ → ('CVCᵊ)Cᵊ

/CəCVCə/ → Cᵊ('CVCᵊ)

/CəCəCV/ → CᵊCᵊ('CV)

/CəCəCə/ → CᵊCᵊ('Cə)

The number of rankings that produce these mappings is:12

They all share the following rankings:

- Trochee » *μ/ə, FtBinμ, AllFtR, Iamb, AllFtL, FtBinσ, Hd-σ
- *μ/ə » FtBinμ, AllFtR, Iamb, AllFtL, FtBinσ, Hd-σ
- FtBinμ » AllFtR, Iamb, AllFtL, FtBinσ
- AllFtR » Iamb, AllFtL, FtBinσ
- Iamb » AllFtL, FtBinσ

Group #56

The following grammars have these IO pairs:

/CVCVCV/ → CV('CVCV)

/CVCVCə/ → ('CVCV)Cᵊ

/CVCəCV/ → ('CVCᵊ)CV

/CəCVCV/ → Cᵊ('CVCV)

/CVCəCə/ → ('CVCᵊ)Cᵊ

/CəCVCə/ → Cᵊ('CVCᵊ)

/CəCəCV/ → CᵊCᵊ('CV)

/CəCəCə/ → Cᵊ('CəCᵊ)

The number of rankings that produce these mappings is:42

They all share the following rankings:

- Trochee » *μ/ə, FtBinμ, FtBinσ, AllFtR, AllFtL, Iamb, Hd-σ
- *μ/ə » FtBinμ, FtBinσ, AllFtR, AllFtL, Iamb, Hd-σ
- FtBinμ » AllFtR, AllFtL
- FtBinσ » AllFtR, AllFtL, Iamb
- AllFtR » AllFtL

Group #57
The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → CVCᵊ('CV)
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → Cᵊ('CV)Cᵊ
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → CᵊCᵊ('Cə)
The number of rankings that produce these mappings is:18
They all share the following rankings:
- Trochee » *μ/ə, FtBinμ, Iamb, AllFtR, AllFtL, FtBinσ, Hd-σ
- *μ/ə » FtBinμ, Iamb, AllFtR, AllFtL, FtBinσ, Hd-σ
- FtBinμ » Iamb, AllFtR, AllFtL, FtBinσ
- Iamb » AllFtR, AllFtL, FtBinσ
- AllFtR » AllFtL

Group #58
The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → CV('CVCᵊ)
/CVCəCV/ → ('CVCᵊ)CV
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → Cᵊ('CəCᵊ)
The number of rankings that produce these mappings is:48
They all share the following rankings:
- Trochee » *μ/ə, FtBinσ, AllFtR, AllFtL, FtBinμ, Iamb, Hd-σ
- *μ/ə » FtBinσ, AllFtR, AllFtL, FtBinμ, Iamb, Hd-σ
- FtBinσ » AllFtR, AllFtL, FtBinμ, Iamb
- AllFtR » AllFtL, FtBinμ

Group #59
The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → ('CV)CᵊCV
/CəCVCV/ → (Cᵊ'CV)CV
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → Cᵊ(Cᵊ'CV)

/CəCəCə/ → (Cᵊ'Cə)Cᵊ

The number of rankings that produce these mappings is:96

They all share the following rankings:

- Iamb » *μ/ə, AllFtL, AllFtR, FtBinμ, FtBinσ, Trochee, Hd-σ
- *μ/ə » AllFtL, AllFtR, FtBinμ, FtBinσ, Trochee, Hd-σ
- AllFtL » AllFtR, FtBinμ, FtBinσ, Trochee

Group #60

The following grammars have these IO pairs:

/CVCVCV/ → (CV'CV)CV

/CVCVCə/ → (CV'CV)Cᵊ

/CVCəCV/ → ('CV)CᵊCV

/CəCVCV/ → (Cᵊ'CV)CV

/CVCəCə/ → ('CV)CᵊCᵊ

/CəCVCə/ → (Cᵊ'CV)Cᵊ

/CəCəCV/ → Cᵊ(Cᵊ'CV)

/CəCəCə/ → ('Cə)CᵊCᵊ

The number of rankings that produce these mappings is:12

They all share the following rankings:

- Iamb » *μ/ə, AllFtL, FtBinμ, Trochee, AllFtR, FtBinσ, Hd-σ
- *μ/ə » AllFtL, FtBinμ, Trochee, AllFtR, FtBinσ, Hd-σ
- AllFtL » FtBinμ, Trochee, AllFtR, FtBinσ
- FtBinμ » Trochee, AllFtR, FtBinσ
- Trochee » AllFtR, FtBinσ

Group #61

The following grammars have these IO pairs:

/CVCVCV/ → CV(CV'CV)

/CVCVCə/ → (CV'CV)Cᵊ

/CVCəCV/ → CV(Cᵊ'CV)

/CəCVCV/ → Cᵊ(CV'CV)

/CVCəCə/ → ('CV)CᵊCᵊ

/CəCVCə/ → (Cᵊ'CV)Cᵊ

/CəCəCV/ → Cᵊ(Cᵊ'CV)

/CəCəCə/ → Cᵊ(Cᵊ'Cə)

The number of rankings that produce these mappings is:210

They all share the following rankings:

- Iamb » *μ/ə, AllFtR, AllFtL, FtBinμ, FtBinσ, Trochee, Hd-σ
- *μ/ə » AllFtR, AllFtL, FtBinμ, FtBinσ, Trochee, Hd-σ
- AllFtR » AllFtL

Group #62

The following grammars have these IO pairs:

/CVCVCV/ → CV(CV'CV)

/CVCVCə/ → (CV'CV)Cᵊ

/CVCəCV/ → CVCᵊ('CV)

/CəCVCV/ → Cᵊ(CV'CV)

/CVCəCə/ → ('CV)CᵊCᵊ

/CəCVCə/ → Cᵊ('CV)Cᵊ

/CəCəCV/ → CᵊCᵊ('CV)

/CəCəCə/ → CᵊCᵊ('Cə)

The number of rankings that produce these mappings is:42

They all share the following rankings:

- Iamb » *μ/ə, AllFtR, FtBinμ, Trochee, AllFtL, FtBinσ, Hd-σ
- *μ/ə » AllFtR, FtBinμ, Trochee, AllFtL, FtBinσ, Hd-σ
- AllFtR » AllFtL
- FtBinμ » Trochee, AllFtL, FtBinσ
- Trochee » AllFtL, FtBinσ

Group #63

The following grammars have these IO pairs:

/CVCVCV/ → (CV'CV)CV

/CVCVCə/ → (CV'CV)Cᵊ

/CVCəCV/ → ('CV)CᵊCV

/CəCVCV/ → Cᵊ(CV'CV)

/CVCəCə/ → ('CV)CᵊCᵊ

/CəCVCə/ → (Cᵊ'CV)Cᵊ

/CəCəCV/ → Cᵊ(Cᵊ'CV)

/CəCəCə/ → (Cᵊ'Cə)Cᵊ

The number of rankings that produce these mappings is:24

They all share the following rankings:

- Iamb » *μ/ə, FtBinμ, AllFtL, AllFtR, FtBinσ, Trochee, Hd-σ
- *μ/ə » FtBinμ, AllFtL, AllFtR, FtBinσ, Trochee, Hd-σ
- FtBinμ » AllFtL, AllFtR, FtBinσ, Trochee
- AllFtL » AllFtR, FtBinσ, Trochee

Group #64

The following grammars have these IO pairs:

/CVCVCV/ → (CV'CV)CV

/CVCVCə/ → (CV'CV)Cᵊ

/CVCəCV/ → ('CV)CᵊCV

/CəCVCV/ → Cᵊ(CV'CV)

/CVCəCə/ → ('CV)CᵊCᵊ

/CəCVCə/ → (Cᵊ'CV)Cᵊ

/CəCəCV/ → Cᵊ(Cᵊ'CV)

/CəCəCə/ → ('Cə)CᵊCᵊ

The number of rankings that produce these mappings is:12

They all share the following rankings:

- Iamb » *μ/ə, FtBinμ, AllFtL, Trochee, AllFtR, FtBinσ, Hd-σ
- *μ/ə » FtBinμ, AllFtL, Trochee, AllFtR, FtBinσ, Hd-σ

● FtBinμ » AllFtL, Trochee, AllFtR, FtBinσ
● AllFtL » Trochee, AllFtR, FtBinσ
● Trochee » AllFtR, FtBinσ

Group #65

The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → CV(Cᵊ'CV)
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → Cᵊ(Cᵊ'CV)
/CəCəCə/ → (Cᵊ'Cə)Cᵊ
The number of rankings that produce these mappings is:42
They all share the following rankings:
● Iamb » *μ/ə, FtBinμ, FtBinσ, AllFtL, AllFtR, Trochee, Hd-σ
● *μ/ə » FtBinμ, FtBinσ, AllFtL, AllFtR, Trochee, Hd-σ
● FtBinμ » AllFtL, AllFtR
● FtBinσ » AllFtL, AllFtR, Trochee
● AllFtL » AllFtR

Group #66

The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → ('CV)CᵊCV
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → Cᵊ('CV)Cᵊ
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → ('Cə)CᵊCᵊ
The number of rankings that produce these mappings is:18
They all share the following rankings:
● Iamb » *μ/ə, FtBinμ, Trochee, AllFtL, AllFtR, FtBinσ, Hd-σ
● *μ/ə » FtBinμ, Trochee, AllFtL, AllFtR, FtBinσ, Hd-σ
● FtBinμ » Trochee, AllFtL, AllFtR, FtBinσ
● Trochee » AllFtL, AllFtR, FtBinσ
● AllFtL » AllFtR

Group #67

The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → CV(Cᵊ'CV)

/CəCVCV/ → (Cᵊ'CV)CV
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → Cᵊ(Cᵊ'CV)
/CəCəCə/ → (Cᵊ'Cə)Cᵊ
The number of rankings that produce these mappings is:48
They all share the following rankings:
- Iamb » *μ/ə, FtBinσ, AllFtL, AllFtR, FtBinμ, Trochee, Hd-σ
- *μ/ə » FtBinσ, AllFtL, AllFtR, FtBinμ, Trochee, Hd-σ
- FtBinσ » AllFtL, AllFtR, FtBinμ, Trochee
- AllFtL » AllFtR, FtBinμ

Group #68
The following grammars have these IO pairs:
/CVCVCV/ → ('CVCV)CV
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → ('CV)CᵊCV
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → (CᵊCᵊ)CV
/CəCəCə/ → (CᵊCᵊ)Cᵊ
The number of rankings that produce these mappings is:14
They all share the following rankings:
- *μ/ə » FtBinμ, AllFtL, Trochee, Iamb, AllFtR, FtBinσ, Hd-σ
- FtBinμ » AllFtL, Trochee, Iamb, AllFtR, FtBinσ
- AllFtL » Trochee, Iamb, AllFtR, FtBinσ
- Trochee » Iamb, AllFtR, FtBinσ
- Iamb » AllFtR, FtBinσ

Group #69
The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → ('CV)CᵊCV
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → (CᵊCᵊ)CV
/CəCəCə/ → (CᵊCᵊ)Cᵊ
The number of rankings that produce these mappings is:42
They all share the following rankings:
- *μ/ə » FtBinμ, AllFtL, Iamb, AllFtR, FtBinσ, Trochee, Hd-σ
- FtBinμ » AllFtL, Iamb, AllFtR, FtBinσ, Trochee
- AllFtL » Iamb, AllFtR, FtBinσ, Trochee

● Iamb » AllFtR, FtBinσ, Trochee

Group #70
The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → CVCᵊ('CV)
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → CV(CᵊCᵊ)
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → Cᵊ(CᵊCᵊ)
The number of rankings that produce these mappings is:42
They all share the following rankings:
● *μ/ə » FtBinμ, AllFtR, Trochee, AllFtL, FtBinσ, Iamb, Hd-σ
● FtBinμ » AllFtR, Trochee, AllFtL, FtBinσ, Iamb
● AllFtR » Trochee, AllFtL, FtBinσ, Iamb
● Trochee » AllFtL, FtBinσ, Iamb

Group #71
The following grammars have these IO pairs:
/CVCVCV/ → CV(CV'CV)
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → CVCᵊ('CV)
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → CV(CᵊCᵊ)
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → Cᵊ(CᵊCᵊ)
The number of rankings that produce these mappings is:14
They all share the following rankings:
● *μ/ə » FtBinμ, AllFtR, Iamb, Trochee, AllFtL, FtBinσ, Hd-σ
● FtBinμ » AllFtR, Iamb, Trochee, AllFtL, FtBinσ
● AllFtR » Iamb, Trochee, AllFtL, FtBinσ
● Iamb » Trochee, AllFtL, FtBinσ
● Trochee » AllFtL, FtBinσ

Group #72
The following grammars have these IO pairs:
/CVCVCV/ → ('CVCV)CV
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → ('CVCᵊ)CV
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CVCᵊ)Cᵊ

/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → (CᵊCᵊ)Cᵊ
The number of rankings that produce these mappings is:294
They all share the following rankings:
- *μ/ə » FtBinμ, Trochee, AllFtL, AllFtR, FtBinσ, Iamb, Hd-σ
- Trochee » AllFtL, AllFtR, FtBinσ, Iamb
- AllFtL » AllFtR

Group #73
The following grammars have these IO pairs:
/CVCVCV/ → ('CVCV)CV
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → ('CV)CᵊCV
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → Cᵊ('CV)Cᵊ
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → (CᵊCᵊ)Cᵊ
The number of rankings that produce these mappings is:84
They all share the following rankings:
- *μ/ə » FtBinμ, Trochee, AllFtL, Iamb, AllFtR, FtBinσ, Hd-σ
- FtBinμ » Iamb, AllFtR, FtBinσ
- Trochee » AllFtL, Iamb, AllFtR, FtBinσ
- AllFtL » AllFtR
- Iamb » AllFtR, FtBinσ

Group #74
The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → ('CVCV)Cᵊ
/CVCəCV/ → CVCᵊ('CV)
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → Cᵊ(CᵊCᵊ)
The number of rankings that produce these mappings is:84
They all share the following rankings:
- *μ/ə » FtBinμ, Trochee, AllFtR, AllFtL, FtBinσ, Iamb, Hd-σ
- FtBinμ » AllFtR, AllFtL, FtBinσ, Iamb
- Trochee » AllFtR, AllFtL, FtBinσ, Iamb
- AllFtR » AllFtL, FtBinσ, Iamb

Group #75

The following grammars have these IO pairs:

/CVCVCV/ → CV('CVCV)

/CVCVCə/ → ('CVCV)Cᵊ

/CVCəCV/ → ('CVCᵊ)CV

/CəCVCV/ → Cᵊ('CVCV)

/CVCəCə/ → ('CVCᵊ)Cᵊ

/CəCVCə/ → Cᵊ('CVCᵊ)

/CəCəCV/ → CᵊCᵊ('CV)

/CəCəCə/ → Cᵊ(CᵊCᵊ)

The number of rankings that produce these mappings is:70

They all share the following rankings:

- *μ/ə » FtBinμ, Trochee, FtBinσ, AllFtR, AllFtL, Iamb, Hd-σ
- FtBinμ » AllFtR, AllFtL
- Trochee » FtBinσ, AllFtR, AllFtL, Iamb
- FtBinσ » AllFtR, AllFtL, Iamb
- AllFtR » AllFtL

Group #76

The following grammars have these IO pairs:

/CVCVCV/ → CV('CVCV)

/CVCVCə/ → ('CVCV)Cᵊ

/CVCəCV/ → CVCᵊ('CV)

/CəCVCV/ → Cᵊ('CVCV)

/CVCəCə/ → ('CV)CᵊCᵊ

/CəCVCə/ → Cᵊ('CV)Cᵊ

/CəCəCV/ → CᵊCᵊ('CV)

/CəCəCə/ → Cᵊ(CᵊCᵊ)

The number of rankings that produce these mappings is:42

They all share the following rankings:

- *μ/ə » FtBinμ, Trochee, Iamb, AllFtR, AllFtL, FtBinσ, Hd-σ
- FtBinμ » Iamb, AllFtR, AllFtL, FtBinσ
- Trochee » Iamb, AllFtR, AllFtL, FtBinσ
- Iamb » AllFtR, AllFtL, FtBinσ
- AllFtR » AllFtL

Group #77

The following grammars have these IO pairs:

/CVCVCV/ → (CV'CV)CV

/CVCVCə/ → (CV'CV)Cᵊ

/CVCəCV/ → ('CV)CᵊCV

/CəCVCV/ → Cᵊ(CV'CV)

/CVCəCə/ → ('CV)CᵊCᵊ

/CəCVCə/ → (Cᵊ'CV)Cᵊ

/CəCəCV/ → Cᵊ(Cᵊ'CV)

/CəCəCə/ → (CᵊCᵊ)Cᵊ

The number of rankings that produce these mappings is:84

They all share the following rankings:

● *μ/ə » FtBinμ, Iamb, AllFtL, AllFtR, FtBinσ, Trochee, Hd-σ

● FtBinμ » AllFtL, AllFtR, FtBinσ, Trochee

● Iamb » AllFtL, AllFtR, FtBinσ, Trochee

● AllFtL » AllFtR, FtBinσ, Trochee

Group #78

The following grammars have these IO pairs:

/CVCVCV/ → CV(CV'CV)

/CVCVCə/ → (CV'CV)Cᵊ

/CVCəCV/ → CV(Cᵊ'CV)

/CəCVCV/ → Cᵊ(CV'CV)

/CVCəCə/ → ('CV)CᵊCᵊ

/CəCVCə/ → (Cᵊ'CV)Cᵊ

/CəCəCV/ → Cᵊ(Cᵊ'CV)

/CəCəCə/ → Cᵊ(CᵊCᵊ)

The number of rankings that produce these mappings is:294

They all share the following rankings:

● *μ/ə » FtBinμ, Iamb, AllFtR, AllFtL, FtBinσ, Trochee, Hd-σ

● Iamb » AllFtR, AllFtL, FtBinσ, Trochee

● AllFtR » AllFtL

Group #79

The following grammars have these IO pairs:

/CVCVCV/ → CV(CV'CV)

/CVCVCə/ → (CV'CV)Cᵊ

/CVCəCV/ → CVCᵊ('CV)

/CəCVCV/ → Cᵊ(CV'CV)

/CVCəCə/ → ('CV)CᵊCᵊ

/CəCVCə/ → Cᵊ('CV)Cᵊ

/CəCəCV/ → CᵊCᵊ('CV)

/CəCəCə/ → Cᵊ(CᵊCᵊ)

The number of rankings that produce these mappings is:84

They all share the following rankings:

● *μ/ə » FtBinμ, Iamb, AllFtR, Trochee, AllFtL, FtBinσ, Hd-σ

● FtBinμ » Trochee, AllFtL, FtBinσ

● Iamb » AllFtR, Trochee, AllFtL, FtBinσ

● AllFtR » AllFtL

● Trochee » AllFtL, FtBinσ

Group #80

The following grammars have these IO pairs:

/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → CV(Cᵊ'CV)
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → Cᵊ(Cᵊ'CV)
/CəCəCə/ → (CᵊCᵊ)Cᵊ

The number of rankings that produce these mappings is:70
They all share the following rankings:
- *μ/ə » FtBinμ, Iamb, FtBinσ, AllFtL, AllFtR, Trochee, Hd-σ
- FtBinμ » AllFtL, AllFtR
- Iamb » FtBinσ, AllFtL, AllFtR, Trochee
- FtBinσ » AllFtL, AllFtR, Trochee
- AllFtL » AllFtR

Group #81

The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → ('CV)CᵊCV
/CəCVCV/ → Cᵊ(CV'CV)
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → Cᵊ('CV)Cᵊ
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → (CᵊCᵊ)Cᵊ

The number of rankings that produce these mappings is:42
They all share the following rankings:
- *μ/ə » FtBinμ, Iamb, Trochee, AllFtL, AllFtR, FtBinσ, Hd-σ
- FtBinμ » Trochee, AllFtL, AllFtR, FtBinσ
- Iamb » Trochee, AllFtL, AllFtR, FtBinσ
- Trochee » AllFtL, AllFtR, FtBinσ
- AllFtL » AllFtR

Group #82

The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → CV('CVCᵊ)
/CVCəCV/ → CVCᵊ('CV)
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → Cᵊ(CᵊCᵊ)

The number of rankings that produce these mappings is:126
They all share the following rankings:
- *μ/ə » Trochee, AllFtR, AllFtL, FtBinμ, FtBinσ, Iamb, Hd-σ
- Trochee » AllFtR, AllFtL, FtBinμ, FtBinσ, Iamb
- AllFtR » AllFtL, FtBinμ, FtBinσ, Iamb

Group #83
The following grammars have these IO pairs:
/CVCVCV/ → CV('CVCV)
/CVCVCə/ → CV('CVCᵊ)
/CVCəCV/ → ('CVCᵊ)CV
/CəCVCV/ → Cᵊ('CVCV)
/CVCəCə/ → ('CVCᵊ)Cᵊ
/CəCVCə/ → Cᵊ('CVCᵊ)
/CəCəCV/ → CᵊCᵊ('CV)
/CəCəCə/ → Cᵊ(CᵊCᵊ)
The number of rankings that produce these mappings is:56
They all share the following rankings:
- *μ/ə » Trochee, FtBinσ, AllFtR, AllFtL, FtBinμ, Iamb, Hd-σ
- Trochee » FtBinσ, AllFtR, AllFtL, FtBinμ, Iamb
- FtBinσ » AllFtR, AllFtL, FtBinμ, Iamb
- AllFtR » AllFtL, FtBinμ

Group #84
The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → ('CV)CᵊCV
/CəCVCV/ → (Cᵊ'CV)CV
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → Cᵊ(Cᵊ'CV)
/CəCəCə/ → (CᵊCᵊ)Cᵊ
The number of rankings that produce these mappings is:126
They all share the following rankings:
- *μ/ə » Iamb, AllFtL, AllFtR, FtBinμ, FtBinσ, Trochee, Hd-σ
- Iamb » AllFtL, AllFtR, FtBinμ, FtBinσ, Trochee
- AllFtL » AllFtR, FtBinμ, FtBinσ, Trochee

Group #85
The following grammars have these IO pairs:
/CVCVCV/ → (CV'CV)CV
/CVCVCə/ → (CV'CV)Cᵊ
/CVCəCV/ → CV(Cᵊ'CV)

/CəCVCV/ → (Cᵊ'CV)CV
/CVCəCə/ → ('CV)CᵊCᵊ
/CəCVCə/ → (Cᵊ'CV)Cᵊ
/CəCəCV/ → Cᵊ(Cᵊ'CV)
/CəCəCə/ → (CᵊCᵊ)Cᵊ

The number of rankings that produce these mappings is:56

They all share the following rankings:

● *μ/ə » Iamb, FtBinσ, AllFtL, AllFtR, FtBinμ, Trochee, Hd-σ
● Iamb » FtBinσ, AllFtL, AllFtR, FtBinμ, Trochee
● FtBinσ » AllFtL, AllFtR, FtBinμ, Trochee
● AllFtL » AllFtR, FtBinμ

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